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APOLLO

GUIDANCE AND NAVIGATION

Approved: John M Dahlen Date: 9 May 66
JOHN M. DAHLEN, DIRECTOR, SYS. OPERATIONS
APOLLO GUIDANCE AND NAVIGATION PROGRAM

Approved: David G. Hoag Date: 9 May 66
DAVID G. HOAG, DIRECTOR
APOLLO GUIDANCE AND NAVIGATION PROGRAM

Approved: Ralph R. Ragan Date: 9 May 66
RALPH R. RAGAN, DEPUTY DIRECTOR
INSTRUMENTATION LABORATORY

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R-477 (Rev. 3)

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GUIDANCE AND NAVIGATION SYSTEM OPERATIONS PLAN APOLLO MISSION 202

April 1966

by John M. Dahlen
Malcolm W. Johnston
Albrecht Kosmala
Frederick D. Grant
Daniel J. Lickly
Raymond H. Morth
John R. Rhode
John T. Shillingford
Balraj Sokkappa

MIT INSTRUMENTATION LABORATORY
CAMBRIDGE 39, MASSACHUSETTS

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TABLE OF CONTENTS

Alteration of technical content since R-477, January 1965 had been indicated by "(Rev. 1 - 7/65)" at bottom of respective pages. Alteration since Rev. 1 had been indicated by "(Rev. 2 - 9/65)". In this revision, because of the re-arrangement of Sections, all pages have been noted "(Rev. 3 - 2/66)", whether or not any alteration of pages has been made.

1. INTRODUCTION

1.1 Purpose

This plan governs the operation of the Guidance and Navigation System and defines its functional interface with the spacecraft and ground support systems on Mission 202.

1.2 Authority

This plan constitutes a control document to govern the implementation of:

(1) Detailed G&N flight test objectives
(2) G&N interfaces with the spacecraft and launch vehicle
(3) Digital UPLINK to the Apollo Guidance Computer (AGC)
(4) AGC logic and timeline for spacecraft control*
(5) Guidance and navigation equations*
(6) Digital DOWNLINK from the AGC
(7) G&N System configuration

Revisions to this plan which reflect changes in control items (1) through (7) require approval of the NASA Configuration Control Board.

This plan also constitutes an information document to define:

(1) Trajectory uncertainties due to G&N component errors (Error Analysis)
(2) Trajectory deviations due to spacecraft performance variations and launch vehicle cut-off dispersions (Performance Analysis)
(3) G&N instrumentation (PCM telemetry and on-board recording) exclusive of AGC DOWNLINK
(4) External tracking data requirements

Revisions to this plan which reflect changes in information items (1) through (4) will not require approval of the NASA CCB.

This revision (Rev. 3) contains a comprehensive description of the logic and equations contained in the released flight computer program, 202*REL 1, Revision 0 (NASA No. 101106-011).

*To support these functions this document contains a Control Data section which defines the reference trajectory, AGC memory data and applicable mission data (mass, propulsion, aerodynamic and SCS data)

2. G&N FLIGHT OPERATIONS SUMMARY

This section defines the mission plan as originated by NASA and summarizes the manner in which the G&N system will operate to implement this plan as developed by MIT in cooperation with NASA and NAA/S&ID. This section is divided into three parts:

Par 2.1 Test Objectives

Par 2.2 Spacecraft and Mission Control

Par 2.3 Mission Description

2.1 Test Objectives

2.1.1 Spacecraft Test Objectives which require proper operation of G&N System:

1) Evaluate the thermal performance of the CM heat shield ablator during a high heat load, long duration entry.
2) Demonstrate CM adequacy for manned entry from low earth orbit.
3) Determine nominal mode separation characteristics of the CSM from the SIVB and the CM from the SM.
4) Demonstrate multiple SPS restart (after the second major burn, two 3 second burns with 10 second intervals between burns are required).
5) Determine performance of CSM systems: G&N, SCS, ECS (pressure and temperature control), EPS, RCS and Telecommunications.

2.1.2 Detailed G&N Test Objectives

1) Evaluate performance of the following integrated G&N/Spacecraft modes of operation:
   a. Boost Monitor
   b. Thrust Vector Control
   c. Orbit Attitude Control
   d. Lift Vector Control
   e. Unmanned Spacecraft Control

2) Determine accuracy of G&N system in computation of spacecraft position and velocity during all mission phases.

2.2 Spacecraft & Mission Control

2.2.1 Spacecraft Control

Spacecraft Control is implemented by the Apollo Guidance Computer (AGC) provided by MIT and the Mission Control Programmer (MCP) provided by NAA/S&ID. Basically, the MCP performs those non-guidance functions that would otherwise be performed by the crew, while the AGC initiates major modes which are dependent upon trajectory or guidance functions.

The function interface between the AGC and the MCP is complex and its description is deferred until Section 4. The electrical interface is simple, being relay contacts in the AGC DSKY wired to the MCP, and is described in ICD MH01-01200-216. The following AGC output discrete signals are provided:

1) G&N ATT. CONTR. MODE SELECT
2) G&N ENTRY MODE SELECT
3) G&N ΔV MODE SELECT
4) +X TRANSLATION ON/OFF
5) CM/SM SEPARATION COMMAND
6) FDAI ALIGN
7) T/C ANTENNA SWITCH (deleted; refer to section 3.2.2 section 7)
8) G&N FAIL INDICATION
9) 0.05 g INDICATION
10) GIMBAL MOTOR POWER ON/OFF (deleted; refer to section 3.2.2 section 10)
11) BACKUP ABORT COMMAND

2.2.2 Mission Control

Mission Control is provided by the Houston Mission Control Center (MCC) via the Digital Command System (DCS), which has many discrete inputs to the spacecraft and an UPLINK to the AGC. The discrete commands to the spacecraft and the AGC UPLINK are described in Section 3.

The AGC UPLINK provides MCC with the capability to enter the AGC with any instruction or data which can be entered by the crew via the DSKY keyboard. It is not planned to utilize this full capability for mission 202 however. It is specifically planned to use this link only as described in section 3.3.

2.2.3 Guidance Errors

The performance of the G&N system for mission 202 has been estimated with and without navigation data inserted via the AGC UPLINK.

The most significant G&N error is that error in the critical path angle at entry. The next most significant error is manifested in the CEP at splash.

A complete breakdown of G&N errors is given in Section 7.

2.3 Mission Description

The purpose of this section is to describe G&N functions during each mission phase. Note that these functions are described in greater detail, sufficient to specify the AGC program, in Section 4.

The reference trajectory is defined in Section 6 in sufficient detail to satisfy MIT's requirements for development of guidance equations, spacecraft control logic and determination of flight environment.

Section 8 presents those path and attitude characteristics resulting from guidance control which are believed to have significant effects on other spacecraft equipment and ground support systems.

The overall mission profile is illustrated in Fig. 6-1 and Table 6-1 and might well be examined at this point.

2.3.1 Pre-Launch

During this phase the IMU stable member is held at a fixed orientation with respect to the earth. The X PIPA input axis is held to the local vertical (up) by torquing the stable member about Y and Z in response to Z and Y PIPA outputs. Azimuth orientation about the X axis is held by a gyro-compassing loop such that the Z PIPA axis points downrange at an azimuth of 104.9901 degrees East of True North. Initial azimuth is verified by tracking a ground target with the G&N Sextant at T_o - 8.5 hours. Upon receipt of the GUIDANCE RELEASE signal from the Saturn I. U. the stable member is released to maintain a fixed orientation in inertial space for the remainder of the mission. In this manner the Saturn and Apollo IMU stable members retain a fixed relative orientation. Also, at the time of GUIDANCE RELEASE, the G&N system starts its computation of position and velocity, which continues until first SPS burn cut-off.

2.3.2 SI Boost

The boost trajectory is described in Fig. 6-2. Upon receipt of the LIFT OFF signal from the Saturn I. U., 5 seconds after GUIDANCE RELEASE, the AGC will command the CDUs to the time history of gimbal angles associated with the nominal SI attitude polynomials. The GUIDANCE RELEASE signal is backed up by the LIFTOFF signal. The CDU outputs after resolution will then represent vehicle attitude errors in spacecraft axes and will be displayed on the FDAI and telemetered to the ground. This SI attitude monitor is a required element of the launch vehicle malfunction detection scheme, and, in association with computed position and velocity, constitute the Boost Monitor data provided by the G&N system during this period.

2.3.3 Staging, Coast and SIVB Boost

The G&N system will not have the capability to control the SIVB. The CDUs will be held until LET jetison at which time they will be switched to the Fine Align Mode. After LET jetison the G&N system will monitor IMU gimbal angles to detect tumbling and will compute the free-fall time to entry interface altitude (280,000 ft.) from present position and velocity. These quantities are used in the Abort Logic and, in association with computed position and velocity, constitute the Boost Monitor data provided by the G&N system during this period.

2.3.4 Aborts from SIVB Boost

Aborts from the boost phase are mechanized in the same way as manned flight aborts whenever possible. G&N control of CSM aborts from SIVB boost is enabled by the MCP 2.5 seconds after start of the MCP SIVB/CSM Separation sequence. Upon receipt of the SIVB/CSM SEPARATION signal from the Mission Event Sequence Controller (MESC) the AGC determines a sequence of events using the control logic given in Section 4. Briefly, the sequence of events is derived from three tests:

A. Has the AGC received the ABORT signal from the ground via the UPLINK?

B. Do the spacecraft body rates exceed the tumbling threshold?

C. Does the free-fall time to entry interface altitude fall below the abort T_{ff} criterion of 160 seconds?

For NO ABORT and NO TUMBLING, the AGC commands a normal sequence and SPS burn to the nominal First Burn aim point as described more fully below.

If the ABORT signal is received and there is NO TUMBLING, the AGC commands an abort separation sequence followed by an SPS abort burn to the downrange Atlantic Recovery Point. Landing area control capability is illustrated on Fig. 6-1 which shows a continuous recovery area and the selected downrange Atlantic Recovery Point. The G&N system will control the thrust and lift vectors to achieve this splash point with the constraint that the spacecraft X axis be directed 35 degrees above the visible horizon during thrusting. A 10 g limit is incorporated in the entry program to minimize excessive g loads.

If the abort occurs too early in the boost phase or at an "unsafe" flight path angle, the selected downrange Atlantic Recovery Point cannot be reached because either (1) there is insufficient fuel in the SM tanks, or (2) the booster cut-off conditions are such that the spacecraft would dip into the atmosphere while thrusting. These two conditions are avoided by test C which is mechanized as an interrupt. If the free-fall time falls below 160 seconds so that test C results in a YES answer, the AGC will command engine shutdown and a CSM attitude maneuver to the CM/SM separation attitude. When the free-fall time to 280,000 ft. altitude falls below 85 seconds the AGC will command CM/SM SEPARATION and CM orientation to the aerodynamic trim attitude. The lift vector will be up during the entry phase. Note that "early" aborts result in splash points within the continuous recovery area.

If TUMBLING is detected the AGC will start the SPS 3.0 seconds after receipt of the SIVB/CSM SEPARATION signal. This will result in stabilization by the SCS rate loops, and SPS cutoff by the AGC when it senses that spacecraft body rates have dropped below the tumbling threshold. Following SPS shutdown the AGC will command the maneuver required to orient to the abort SPS burn attitude (thrust axis 35 degrees above the visible horizon). Upon completion of the attitude maneuver, the AGC will command engine ON and guide to the downrange Atlantic Recovery area. Again as in the non-tumbling abort case the engine will be shutdown if free-fall time drops below 160 seconds. Abort area control is illustrated in Fig. 8-4.

2.3.5 CSM/SIVB Separation

There are two CSM/SIVB separation sequences, a normal sequence and an abort sequence used if tumbling or the abort signal is present. In the normal sequence the SPS is ignited by the AGC a fixed time delay of 12.7 seconds after it receives the CSM/SIVB SEPARATION signal. This time delay permits the RCS ullage thrust to build up enough separation distance to prevent the SPS from damaging the SIVB or upsetting its attitude. On the other hand the time delay is not so long as to cause an unjustified ΔV penalty. After separation the AGC computes the initial SPS thrust attitude and commands the required attitude maneuver. If the spacecraft is not completely oriented at the end of the fixed time delay, the SPS is started anyway and orientation is completed during the first few seconds of the burn. Only when large rates and/or large negative pitch attitude dispersions exist at SIVB cut-off will the fixed time delay be too short to permit completion of spacecraft orientation before SPS ignition.

In the abort separation sequence, the SPS is ignited by the AGC a time delay of 3.0 seconds after it receives the CSM/SIVB SEPARATION signal. This time delay is made as short as possible to minimize the probability of CSM-SIVB recontact or loss of IMU reference in the tumbling case and to get the CSM away from the SIVB as quickly as possible in any abort case.

2.3.6 SPS First Burn

First burn thrust will be controlled by the G&N system to achieve the reference trajectory major axis and eccentricity at cut-off. The trajectory plane at cut-off will include the Pacific Recovery Point at nominal splash time. The steer law used in this maneuver is given in Section 5, where are found all the CSM guidance equations for Mission 202. It will be noted that the universal cross product steering law for Apollo is used whenever possible, specifically, for this mission, in all cases except tumbling arrest and the short third and fourth burns.

2.3.7 Coast Phase, First Burn Cut-off to Second Burn Ignition

Following first burn cut-off the AGC will compute and command a spacecraft attitude maneuver to align the X-axis with the local vertical, nose down, and the Y-axis with the angular momentum vector $R * V$.

At 300.0 seconds after 1st SPS burn cutoff the AGC will command FDAI ALIGN for 10 seconds thereby resetting the backup attitude reference to correct for its accumulated drift error. At this time, the inner gimbal angle will be $96.4^{\circ} \pm 1.0^{\circ}$, the outer gimbal angle will be $179.9^{\circ} \pm 1.0^{\circ}$ and the middle gimbal angle will be $0.8^{\circ} \pm 1.0^{\circ}$.

After a time interval of 2037.2 secs. from first burn cut-off the vehicle attitude in tracking the local vertical will come closest, in the nominal case, to the second burn ignition attitude. At this time the local vertical mode will be terminated. The AGC will then establish the second burn ignition point by a process of precision numerical integration and will compute the second burn ignition attitude. The AGC will then command the vehicle to this attitude, which it will hold inertially until ignition.

2.3.8 Second, Third and Fourth SPS Burns

Second burn ignition occurs after a fixed time delay of 3163.7 seconds from first burn cut-off. The AGC will command + X TRANSLATION 30 seconds before ignition to provide ullage. Thrust is controlled by the G&N system to achieve the reference trajectory major axis and eccentricity at cut-off, and a trajectory plane which includes the Pacific Recovery Point at nominal splash time.

Second burn is terminated by the AGC six seconds before the required velocity is attained. The spacecraft attitude at this time will be held until fourth burn cutoff. During second burn the G&N attitude error signal will develop a bias proportional to the c.g. shift from the engine gimbal trim position set in prior to second burn ignition. After second burn cutoff the CDUs will be moved off from their position at cutoff by a stored estimate of this bias in order to minimize the attitude transient after engine shutdown.

The AGC will start and shutdown the SPS on a time basis so that the last two burns are each of 3 seconds duration and so that the two short coast periods are each of 10 seconds duration. The AGC will control the + X TRANSLATION signal so that the RCS will provide ullage thrust as well as attitude control during the 10-second coast periods. Note that the SCS disables + X translation during SPS firing.

2.3.9 Pre-Entry Sequence

The fourth burn cutoff attitude is held until the free-fall time to 400,000 ft. altitude drops below the normal T_{ff} criterion of 160 seconds, when the G&N system will start pitching the spacecraft up to the CM/SM separation attitude (+ X axis up in the trajectory plane and tipped forward in the direction of motion 60 degrees above the velocity vector). When the free-fall time drops below 85 seconds the AGC will command CM/SM SEPARATION. After a 5-second time delay to allow for separation and stabilization, the G&N system will start orienting the CM to the entry attitude. The CM will then be at the aerodynamic trim angle of attack with roll angle for down lift.

2.3.10 Entry

The velocity and critical flight path angle at entry are directly controlled by the G&N system during the second, third and fourth burns. The entry guidance equations, which are given in Section 5, are designed to provide a trajectory which will satisfy heat shield test objectives while controlling the roll angle so as to splash at the designated Pacific Recovery Point.

2.3.11 Navigation Update

The ground will compare radar tracking data with the AGC state vector transmitted via DOWNLINK after first SPS burn cutoff, and, if necessary, update the AGC during the coast phase. The update is initiated by a Digital Command System message to "accept a navigation update". Upon verification via DOWNLINK that the AGC is ready to receive the data, the DCS loads position, velocity, and time for use in second SPS burn guidance. After verification via DOWNLINK that the data are correctly loaded the DCS will signal the AGC to use the new data. (see Section 3.3)

2.3.12 Flight Simulation Results

Performance of the G&N System and spacecraft on a large set of nominal and aborted missions simulated on the MIT all-digital computer/environment simulation is documented in MIT Report E-1922, "Mission AS-202, AGC Software Verification, Summary of Results of Digital Simulations", February 1966, by Albrecht L. Kosmala.

3. G&N SYSTEM DESCRIPTION

This section defines the specific provisions incorporated in the G&N System to mechanize the required system operations.

3.1 G&N Hardware Configuration

System 017 will be the G&N system for Mission 202. It is a Block I Series 50 system with one modification; the wiring of 11 spare relays and a special failure module in the main DSKY to the MCP to provide the AGC/MCP signal interface. A Block I Series 50 system is comprised of the following assemblies:

(a) Inertial Subsystem — Block I Series 50
- Inertial Measurement Unit (IMU)
- Inertial System CDU's (electro-mechanical)(ICDU's)
- Power Servo Assembly (PSA)
- IMU Control Panel

(b) G&N Harness — Block I Series 50

(c) Computer Subsystem — Block I Series 100
- Apollo Guidance Computer (AGC)
- Display and Keyboard (DSKY - Main Display Console)
- Display and Keyboard (DSKY - Lower Equip. Bay)
- Computer Harness

(d) Optics Subsystem — Block I Series 50
- Scanning Telescope (SCT)
- Sextant (SXT)
- Optical System CDU's (OCDU's)
- Power Servo Assembly (PSA)

Without giving a detailed analysis of each G&N Block configuration, a brief description of each and the reason for its evolution is useful in understanding G&N capability for Mission 202.

Block I is the original G&N design. It is composed of IMU, AGC, PSA, CDU's (mechanical), Harnesses, and OPTICS (sextant and telescope). As the G&N flight requirements became more clearly defined it was apparent that Block I would need modification to qualify for flight.

Block I, Series 100 therefore evolved. It is the Block I system modified generally as follows:

(a) IMU - Vibration dampers added; moisture insulation added.
(b) AGC - Cooling interface modified; humidity proofing added.
(c) PSA - Cooling interface modified; humidity proofing added.
(d) CDU's - Minor electrical and mechanical changes.

(e) Harnesses - All wiring changed to teflon; connectors humidity proofed.

(f) OPTICS - Minor servo modifications.

When the full design and production schedule impact of the Series 100 modifications became clear the Block I Series 50 configuration was originated, being a limited 100 Series modification qualified for flight and available on an early schedule.

Block I Series 50 is basically the Block I Series 100 system less humidity proofing.

3.2 G&N/Spacecraft Signal Interfaces

3.2.1 Interface Controlling Documents (ICD's)

Below are listed the ICD's which are pertinent to an understanding and definition of the operational interfaces between the G&N system and the SC/BOOSTER. The majority of these are electrical ICD's (including in some cases function definitions). All of the additional existing ICD's pertaining to mechanical interfaces, thermal interfaces, material compatibility et cetera have not been listed as they are considered not to be within the scope of this document.

General Interfacing Area	ICD Title	ICD No.	Description
G&N/VEHICLE	Launch Vehicle to G&N Interface	MH01-01278-216	Signal interface and description: (a)GUIDANCE REFERENCE RELEASE (b)LIFTOFF (c)SIVB ULLAGE (deleted for Mission 202)
" "	Vehicle Separation Signals to AGC	MH01-01280-216	Signal interface and description: (a)CSM/SIVB SEPARATION (ABORT) (b)CM/SM SEPARATION (deleted for Mission 202)
G&N/MCP	Outputs - AGC to Mission Control Programmer	MH01-01200-216	For detailed description refer to Section 3.2.2
G&N/SCS	Attitude Error Signal (see Fig. 3-1 also)	MH01-01224-216	Signal interface for: (a)PITCH ERROR (BODY and BODY OFFSET)

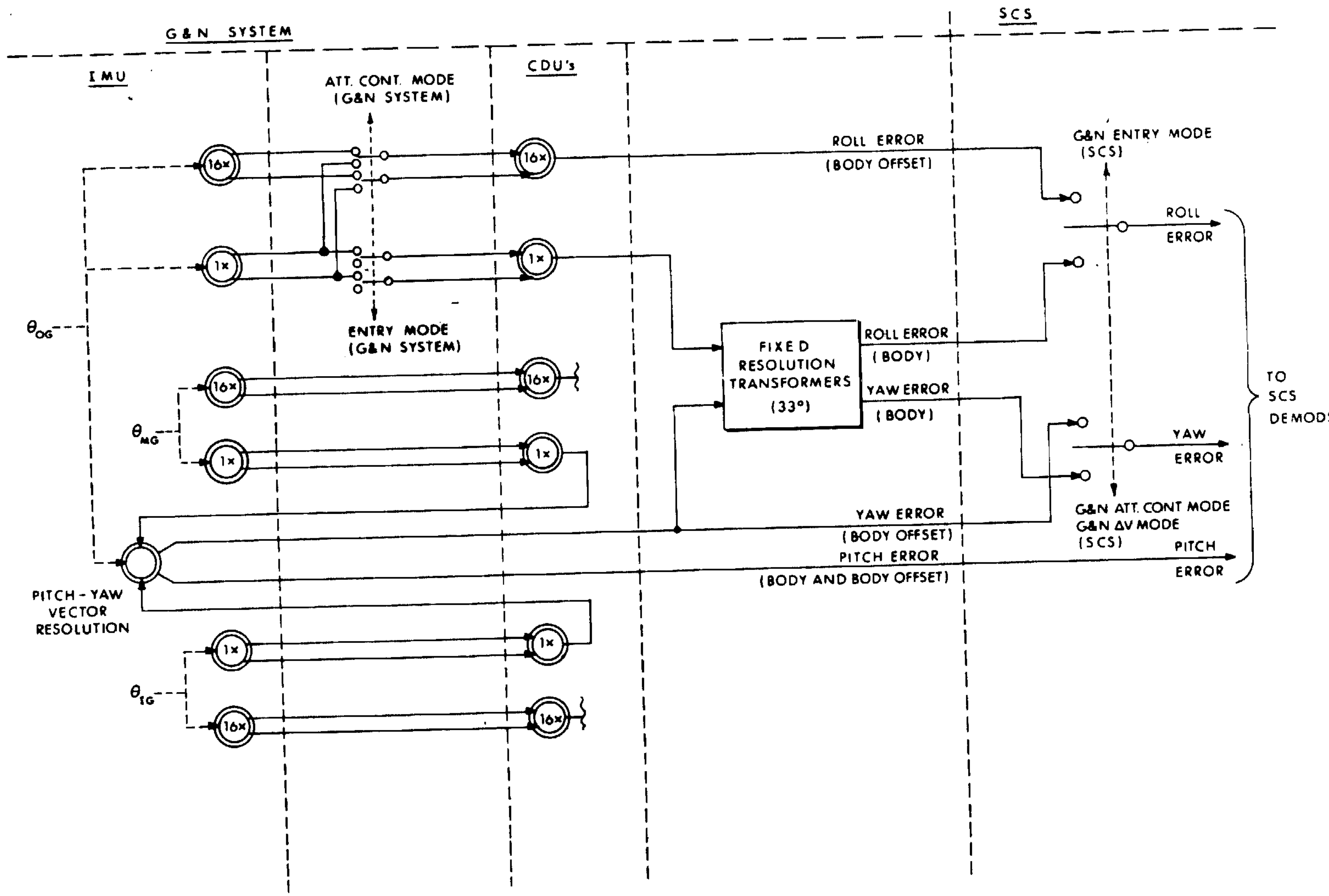


Fig. 3-1 G&N attitude error signal generation to SCS.

General Interfacing Area	ICD Title	ICD No.	Description
			(b) YAW ERROR (BODY) (c) YAW ERROR (BODY OFFSET) (d) ROLL ERROR (BODY) (e) ROLL ERROR (BODY OFFSET) (f) ERROR SIGNAL REFERENCE
" "	Total Attitude Signals	MH01-01225-216	Signal interface for: (a) SINE AIG (b) COS AIG (c) SINE AMG (d) COS AMG (e) SIN AOG (f) COS AOG (g) ATTITUDE SIGNAL REFERENCE
" "	Engine ON-OFF Signal to SCS	MH01-01238-216	Electrical interface for the AGC command to the SPS engine
G&N/UP and DOWN TELEMETRY SYSTEMS	Data transmission to Operational PCM T/M equipment	MH01-01228-216	Electrical interface for all G&N PCM measurements. Should agree with information in Section 3. 5. 3
" "	ACE Uplink, S/C Digital Up Data Link, Apollo Guidance Computer	MH01-01236-200	Electrical interface between AGC and S/C Updata Link Receiving equipment. Used both for receipt of ACE UPLINK transmissions during ground checkout and AGC UPLINK transmissions from ground during flight
" "	G&N Signal Conditioner to S/C Flight Qualification Recorder	MH01-01287-216	Electrical interface for all G&N Flight Qualification Recorder measurements. Should agree with para. 3. 5. 4

General Interfacing Area	ICD Title	ICD No.	Description
G&N/S/C/ POWER	Guidance and Navigation Electrical Input Power	MH01-01227-216	Total AC and DC power specification from S/C for G&N.
MISCEL-LANEOUS	Central Timing Equipment Synchronizing Pulse	MH01-01226-216	Electrical interface for G&N "SYNCH" pulse to S/C Central Timing System.

3.2.2 AGC Outputs to MCP

This interface is documented in ICD No. MH01-01200-216 and provides 11 relay closures in the main DSKY and 1 relay closure in the G&N Failure Detection Module. These relays provide functions as described below:

(1) G&N ATTITUDE CONTROL MODE SELECT

Control Mode selection in the SCS.

(2) G&N ENTRY MODE SELECT

Control Mode selection in the SCS.

(3) G&N ΔV MODE SELECT

Control Mode Selection in the SCS.

(4) +X TRANSLATION ON/OFF

To control the application of +X translation.

(5) CM/SM SEPATATION COMMAND

To initiate the MESC controlled CM/SM Separation Sequence.

(6) FDAI ALIGN

Commands the backup attitude reference system (BMAG's caged to AGCU) to a zero reference determined by the current vehicle attitude. When initiated, the signal will be continued for 10 seconds.

(7) T/C ANTENNA SWITCH

The requirement for AGC control of T/C antenna switching has been deleted. This AGC output relay is now a spare; however its arming is under the control of the MCP, subject to the original logic designed for the T/C ANTENNA SWITCH function. (Refer Figure 3-2.)

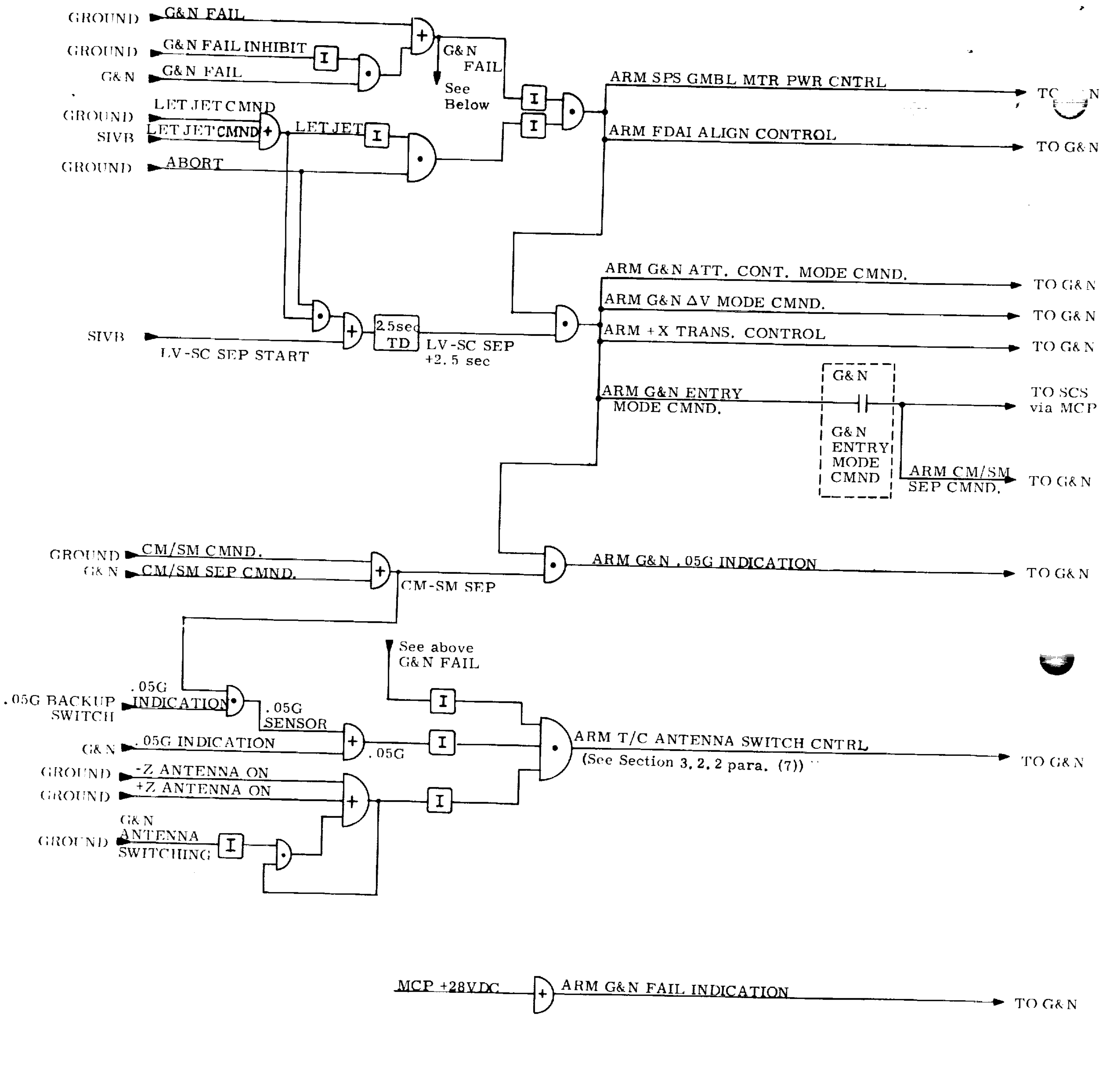


Fig. 3-2 Arming logic for G&N/MCP interface

(8) .05G INDICATION

G&N will sense .05G with the PIPA's, give this indication to the SCS (via the MCP) and the SCS system will inhibit pitch and yaw attitude control on the assumption that these axes will be stabilized by aerodynamic forces. Should the G&N .05G indication not be received by the MCP/SCS, this attitude control would not be inhibited, and if sufficient pitch and yaw attitude errors are generated, RCS fuel would be wasted throughout entry. The G&N entry program will attempt to null the pitch and yaw error signals during entry based on its estimation of the pitch and yaw trim angles of attack. MIT estimates that the resulting pitch and yaw attitude errors will not exceed the deadbands in the SCS. Should this be incorrect RCS fuel loss will occur. The G&N .05 indication is not used within the re-entry program, however, so should this function be backed up by a redundant CM sensor no AGC confusion should result.

(9) GIMBAL MOTOR POWER ON/OFF

The AGC must terminate SPS GIMBAL MOTOR POWER in order to key the MCP to select the appropriate SPS motor gimbal trim inputs. The MCP does this sequentially and therefore the AGC must terminate this command only once after 1st SPS burn (to select trim position for 2nd burn) and once after 2nd SPS burn (to select trim position for 3rd burn). The trim position for the 1st burn is selected by the MCP upon keying from the SIVB/CSM separate command. The 3rd burn trim position is also satisfactory for the 4th burn.

(10) G&N ABORT COMMAND

This command, originally a backup or alternate abort signal to the MCP originated by the AGC in response to an AGC UPLINK command, has been deleted. This relay thus becomes a spare with no assigned function.

(11) SPARE

This is a spare relay with no assigned function.

(12) G&N FAIL INDICATION

This signal is generated by the G&N Failure Detection Module. This module is mounted at the rear of the main DSKY and is electrically interposed between the NAA harness to the DSKY and the DSKY itself. The module operation is described in detail in Section 3.6. Its operation with respect to the total G&N Failure Monitor System is shown in Figure 3-3.

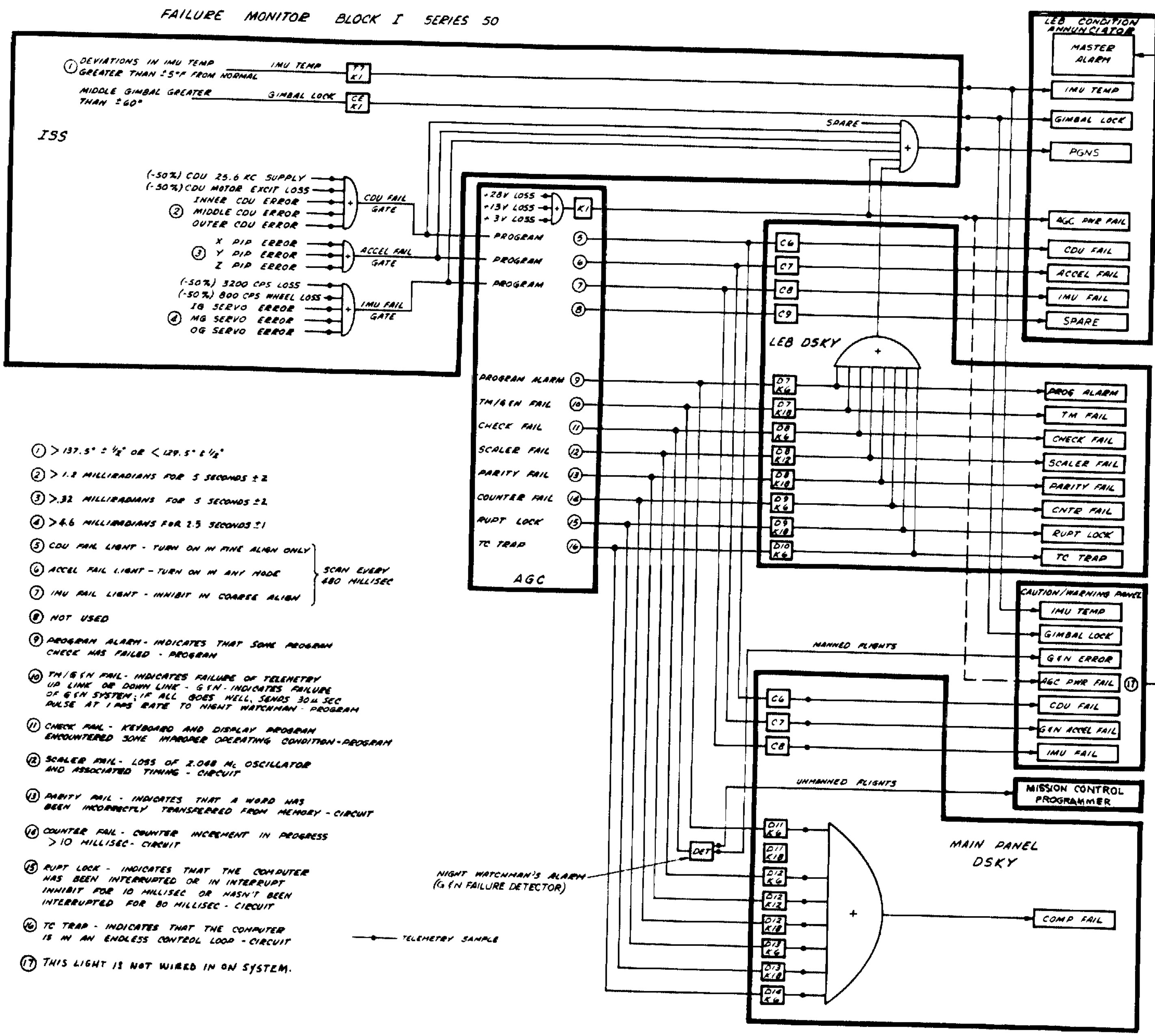


Fig. 3.3 G&N FAILURE MONITOR SYSTEM

3.2.3 Detailed Interface Operation

Certain additional facts are pertinent to the use and comprehension of the AGC/MCP interface:

(1) The AGC must not command more than one SCS mode simultaneously. This requires termination of each mode before commanding the next; 250 ms has been established as sufficient time interval between termination and selection.

(2) The response of the SCS system to the commands and/or indication signals of the AGC via the MCP are subject to the arming of these command/indications by the MCP. The arming logic for the G&N/MCP interface is as shown in Figure 3-2.

(3) In all cases the MCP initiates the SIVB/CSM Separation Sequence. For normal cases its action is keyed upon notification from the Saturn I.U. For boost aborts the ground must command the MCP to start the sequence.

3.3 Digital UPLINK to AGC

By means of the AGC UPLINK, the ground can insert data or instruct the AGC in the same manner normally performed by the crew using the DSKY Keyboard. The AGC will be programmed to accept the following UPLINK inputs:

(1) ABORT INDICATION (required for abort logic as described earlier)

(2) LIFTOFF (backup to discrete input)

(3) SIVB/CSM SEPARATION (backup to discrete input)

(4) POSITION and VELOCITY data (provides ground capability to update navigation data in the AGC).

(5) AGC CLOCK ALIGNMENT

(6) SPS GIMBAL MOTOR POWER ON/OFF

(7) FDAI ALIGN

Operational procedures governing the use of these Uplink inputs must be developed to ensure proper operation within program constraints.

All information received by the AGC from the Uplink is in the form of keyboard characters. Each character transmitted to the AGC is triply redundant. Thus, if C is the 5-bit character code, then the 16-bit message has the form:

$$1C\bar{C}C$$

where $\bar{C}$ denotes the bit-by-bit complement of C. To these 16 bits of information the ground adds a 3-bit code specifiying which system aboard the spacecraft is to be the final recipient of the data and a 3-bit code indicating which spacecraft should receive the information. The 22 total bits are sub-bit encoded (replacing each bit with a 5-bit code for transmission.) If the message is received and successfully decoded, the receiver onboard will send back an 8-bit "message accepted pulse" to the ground and shift the original 16 bits to the AGC ($1C\bar{C}C$).

All uplink words given in this section are in the form transmitted from the uplink receiver to the AGC. Therefore they do not contain the vehicle or sub-system addresses added on by the ground facilities. For the purpose of this section, the following definitions hold:

1. 1 uplinkword = 1 character
2. 5 characters or uplink words = contents of one AGC register
3. 1 downlink word = verification of 1 character or a display change.

3.3.1 ABORT INDICATION - to send an abort message to the AGC, the following special word should be sent via the uplink.

Binary Uplink Word (1 C $\overline{C}$ C)	Equivalent Keyboard Character (C)
1 10011 01100 10011	ABORT

3.3.2. LIFTOFF - to send the backup liftoff discrete to the AGC, the following special word should be sent via the uplink.

1 10001 01110 10001	VERB
1 00111 11000 00111	7
1 00101 11010 00101	5
1 11100 00011 11100	ENTER
1 00011 11100 00011	3
1 11100 00011 11100	ENTER

3.3.3 SIVB/CSM SEPARATION - to send this backup separation discrete to the AGC, the following six words should be sent via the uplink.

1 10001 01110 10001	VERB
1 00111 11000 00111	7
1 00101 11010 00101	5
1 11100 00011 11100	ENTER
1 00100 11011 00100	4
1 11100 00011 11100	

3.3.4 NAVIGATION UPDATE - to begin a navigation update on flight 202 prior to SPS2 burn the following 4 words should be sent via uplink.

1 10001 01110 10001	VERB
1 00111 11000 00111	7
1 00110 11001 00110	6
1 11100 00011 11100	ENTER

The ground station should then await confirmation via Downlink that the AGC is in Major Mode 27.

In Major Mode 27 the AGC will accept a complete ground navigation update in the format to be described below.

The data itself will take the form of three (3) double precision components of position, three (3) double precision components of velocity, and double precision time. The position and velocity components should be given in stable member co-ordinates (see Sec. 2.3.1) and the time should be in the time of the "fix" referenced to AGC CLOCK ZERO. The data must be sent in the following sequence:

XXXXX	(most sig. part of X position)....	ENTER
XXXXX	(least sig. part of X position)....	ENTER
XXXXX	(most sig. part of Y position)....	ENTER
XXXXX	(least sig. part of Y position)....	ENTER
XXXXX	(most sig. part of Z position)....	ENTER
XXXXX	(least sig. part of Z position)....	ENTER
XXXXX	(most sig. part of X velocity)....	ENTER
XXXXX	(least sig. part of X velocity)....	ENTER
XXXXX	(most sig. part of Y velocity)....	ENTER
XXXXX	(least sig. part of Y velocity)....	ENTER
XXXXX	(most sig. part of Z velocity)....	ENTER
XXXXX	(least sig. part of Z velocity)....	ENTER
XXXXX	(most sig. part of time from AGC clock zero)	ENTER
XXXXX	(least sig. part of time from AGC clock zero)...............	ENTER

where each "X" and "ENTER" above represents an uplink word. If, for some reason, the ground wishes to resend any 5 uplink word group before the ENTER associated with that group has been transmitted, the following "CLEAR" word should be sent

1 11110 00001 11110

and the 5 word group retransmitted.

If the ground station wishes to terminate the load before the ENTER associated with the least sig. part of time has been sent, the following 4 uplink words must be sent

Binary UPLINK WORD (1 C $\bar{C}$ C)	Equivalent Keyboard Character (C)
1 10001 01110 10001	VERB
1 00011 11100 00011	3
1 00100 11011 00100	4
1 11100 00011 11100	ENTER

which will return the AGC to the mode it was in before the update was initiated.

After the ENTER associated with the least sig. part of time, the ground station must verify via Downlink that the AGC has correctly received the navigational update before sending another ENTER to signal the AGC that it can use the data in guidance computations.

This entire load must be completed at least 50 sec* before SPS 2 ignition.

If, during the final verification period after the ENTER associated with the least sig. part of time, it is found that the data in the AGC are not correct, the ground station may change the load in either of the following ways.

1) If only a few parts must be changed the ground station should send

Binary Uplink Work (1 C $\bar{C}$ C)	Equivalent Keyboard Character (C)
1 10001 01110 10001	VERB
1 00011 11100 00011	3
1 00100 11011 00100	4
1 11100 00011 11100	ENTER

followed by the relative address of the part to be changed, these addresses run in order from 1 to 16_8 for the 14 parts of the load shown above; i.e. if the least sig. part of the Y velocity were to be changed VERB 34 ENTER should be followed by

1 00001 11110 00001	1
1 00010 11101 00010	2
1 11100 00011 11100	ENTER

then the 5 uplink words corresponding to the part to be changed are sent followed by an ENTER. This procedure, VERB 34 ENTER etc., must be repeated for each part to be changed. When all changes are made and verified via Downlink an additional ENTER must be sent to signal the AGC that it can use the data.

2) If many parts must be reloaded, the ground station may choose to start the load from the beginning. To do

*The state vector may be defined at up to approximately 1000 secs before or after second +X translation time. The capability of integrating this state vector to the +X translation time is reduced by approximately 270 secs each time an AGC restart occurs during the integrating period (+X2 - 20 secs to +X2 - 2 secs).

this during the final verification period after the ENTER associated with the least sig. part of time the ground station must send VERB 34 ENTER followed by another VERB 34 ENTER which will terminate the load and allow the AGC to return to its pre-update condition.

If the AGC receives an improperly coded word from the uplink receiver during the load (not C $\overline{C}$ C) it will turn on bit 4 of OUT 1 which is transmitted via Downlink (see Sec. 8.1.1). When this occurs the ground station should send the following 3 uplink words:

1 00000 00000 00000	(to clear uplink buffer)
1 10010 01101 10010	ERROR RESET
1 11110 00001 11110	CLEAR

The ground station should then begin loading with the first word of the 5 word group it was sending when the alarm condition occured.

If insufficient time remains to SPS 2 + X translation, the AGC will change its major mode and proceed with the internally computed data.

The scale factors for AGC navigational updating are:

position	meters/2^{24}
velocity	(meters/C.S.)/2^{7}
"fix" time	C.S./2^{28}
(1 C.S. = .01 sec)	

The AGC is a fixed pt. machine with the pt. just to the left of the most significant bit.

The scaling indicated above will be sufficient to force the 3 components of position and the 3 components of velocity and time to numbers less than one.

To form the double precision quantities ready for coding and transmission the scaled magnitudes of time and each component of position and velocity should be expressed as two binary words as follows:

1^{st} word	O	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	2^{-8}	2^{-9}	2^{-10}	2^{-11}	2^{-12}	2^{-13}	2^{-14}
2^{nd} word	O	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		2^{-15}	2^{-16}	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}	2^{-24}	2^{-25}	2^{-26}	2^{-27}	2^{-28}

Each X above represents a binary bit of the appropriate magnitude, the place value of which is indicated below the corresponding X. Once the magnitude of the component is accounted for in the above 28 X's, the sign must be considered.

If the component is positive, the words remain as formed; if the component is negative, the "1's complement" of the 2 words is used (all 1's are replaced by 0's and all 0's by 1's).

The first word is then transformed into a 5 character octal word. The first character is the octal equivalent of the first three bits, the second character is the octal equivalent of the next three bits, etc. This word is referred to as the "most significant part" of data in the text above. Similarly the second word is transformed into a 5 character octal word which is the "least significant part" of data.

Each character must now be coded into a 16 bit uplink word for transmission. A table of the characters and their uplink word follows.

3.3.5 AGC CLOCK ALIGN - to align the AGC clock two procedures are required. To set the AGC clock to a specific value, the following uplink words must be sent.

Binary Uplink Word (1 C $\overline{C}$ C)	Equivalent Keyboard Character (C)
1 10001 01110 10001	VERB
1 00010 11101 00010	2
1 00001 11110 00001	1
1 11111 00000 11111	NOUN
1 00001 11110 00001	1
1 00110 11001 00110	6
1 11100 00011 11100	ENTER

This must be followed by ± XXXXX ENTER where each X represents one decimal digit, properly coded (see Table 1) and the total number represents the time in C. S. that will be set into the AGC clock. If it is required to zero the clock, all the X's should be zeros.

TABLE 1

Character	Uplink Word
0	1 10000 01111 10000
1	1 00001 11110 00001
2	1 00010 11101 00010
3	1 00011 11100 00011
4	1 00100 11011 00100
5	1 00101 11010 00101
6	1 00110 11001 00110
7	1 00111 11000 00111
8	1 01000 10111 01000
9	1 01001 10110 01001
VERB	1 10001 01110 10001
NOUN	1 11111 00000 11111
ENTER	1 11100 00011 11100
ERROR RESET	1 10010 01101 10010
CLEAR	1 11110 00001 11110
KEY RELEASE	1 11001 00110 11001
+	1 11010 00101 11010
-	1 11011 00100 11011
ABORT	1 10011 01100 10011

NOTE: It is good operation procedure to end every uplink message with a KEY RELEASE.

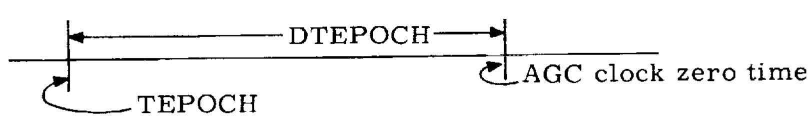
Since there are uncertainties in time of transmission, etc., it is anticipated that a time increment may be needed. To increment the AGC clock, the following uplink words must be sent.

Binary Uplink Word (1 C $\bar{C}$ C)	Equivalent Keyboard Character C
1 10001 01110 10001	VERB
1 00101 11010 00101	5
1 00101 11010 00101	5
1 11100 00011 11100	ENTER

This must be followed by ± XXXXX ENTER where the total number represents the time increment in C.S.

The AGC must have had the latitude, azimuth and time DTEPOCH described below, loaded as three double-precision quantities during eraseable memory initialization. The AGC uses these quantities to generate the matrix which relates the reference inertial coordinate system to the stable member coordinate system. To do this the reference system must be rotated thru the following angles in the order given below.

1) About reference Y-axis thru latitude angle of local vertical.
2) About reference Z-axis thru the angle equal to the earth's angular rate times (DTEPOCH + AGC clock reading at G.R.R.); the Z axis of the reference coordinate must be parallel to the earth's spin axis and TEPOCH must be the time that the local vertical vector passed thru the +X +Z plane of the reference inertial system.
3) About the local vertical vector (the SM desired X-axis) thru the azimuth angle (positive rotation is clockwise looking towards center of the earth).



The following restraints must be observed on the magnitudes of the times shown above.

1) |DTEPOCH + AGC clock| at guidance reference release must be less than 2^{28} C.S. since the AGC must use this time to determine the inertial platform coordinates at guidance reference release.

2) $|$AGC clock$|$ during the flight must be less than 2^{28}C.S. to prevent overflow.

3.3.6 SPS GIMBAL MOTOR POWER ON/OFF - to turn the SPS Gimbal Motors on or off the following message must be sent

V75E Refer to TABLE I
XE for codes

where the X above is a 1 if the motors are to be turned on or a 2 if they are to be turned off.

3.1.2.1.7 FDAI ALIGN - To start an FDAI ALIGN sequence (terminated by program after 10 sec) the following message must be sent

$$\begin{array}{ll} \text{V75E} & \left\{\begin{array}{c}\text{Refer to TABLE I}\\ \text{for codes}\end{array}\right\} \\ \text{5E} & \end{array}$$

3.4 AGC Digital Downlink

The AGC digital downlink consists of 50 words/sec on the high rate and 10 words/sec on the low rate. Each "word" contains 40 bits (a 16-bit register transmitted twice and an 8-bit "word order code"). Since the high rate will be used exclusively for flight 202, all further discussion will use the 50 words/sec rate.

The 40 bits of the word are shown below.

X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	P
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	P
X	X	X	X	X	X	X	X								
			W.O.C.												

where each X above represents a binary bit. The first 15 bits above carry the downlink information and the 16th bit provides odd parity for the first 16 bits. The second 16 bits are an exact reproduction of the first 16. The last eight bits are known as the Word Order Code and are used to distinguish between data words and ID or marker words. All eight-word order code bits are the same (0 for data words, 1 for ID and marker words.)

The digital downlink format is controlled by an AGC program which loads the next word to be transmitted into register OUT4. This program is entered on an interrupt caused by an "endpulse" from the telemetry system.

Before giving details of the AGC downlink a few important points on the downlink should be reviewed. Most of the downlink words are actually the contents of erasable memory registers which are used during the normal computations in the AGC. There is no special buffer set aside for telemetry words because of erasable memory size restrictions. The programs that use these erasable registers have no set phase relationship with the downlink program and, therefore, data which take more than one downlink word to transmit (i.e. double precision words, vectors, etc.) may have words from two different computation cycles. Some of these data arrays are associated with "markers" as explained in the following paragraphs.

Most telemetered parameters have negative numbers represented in ones complement form (exceptions will noted in detailed parameter description to follow). The sign information is carried in bit 15 (1 for minus, 0 for plus) and, in general, the signs of the most and least significant portions will not agree. The procedure for obtaining the sign and magnitude of a double-precision word with sign disagreement is as follows.

The first bit of each word indicates the sign of that word (1 for minus, 0 for plus) and the next 14 bits give the magnitude (in ones complement for minus signs). With double-precision words, the most significant word and the least significant word may have different signs. If either of the words has a magnitude of 0, the complement of that word should be used to force sign agreement. If neither word has a 0 magnitude, the following procedure should be followed. Examples are given for each case using words of 6 bits, 1 sign bit and 5 magnitude bits.

Case 1 Most Significant word sign bit equals 1

Least Significant word sign bit equals 0

Complement magnitude bits of most significant word and subtract magnitude bits of least significant word as in example below. The sign of the total quantity is minus

Most significant word equals 110011

Least significant word equals 001010

	01100	00000
		01010
Minus	(01011	10110)

Case 2 Most significant word sign bit equals 0

Least significant word sign bit equals 1

Complement magnitude bits of least significant word and subtract from most significant word as shown in example below. The sign of the total quantity is plus.

Most significant word equals 010011

Least significant word equals 101010

	10011	00000
		10101
Plus	(10010	01011)

The AGC is a fixed-point machine with the binary point assumed between bit 15 and bit 14. The scale factors included later in this section give the units divided by the proper number to cause the value of the parameter to be less than one. The bit weights for a double-precision word are:

Most Sig:

Sign 2^{-1} 2^{-2} 2^{-3} 2^{-4} 2^{-5} 2^{-6} 2^{-7} 2^{-8} 2^{-9} 2^{-10} 2^{-11} 2^{-12} 2^{-13} 2^{-14}

Bit Number:

15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Least Sig:

Sign 2^{-15} 2^{-16} 2^{-17} 2^{-18} 2^{-19} 2^{-20} 2^{-21} 2^{-22} 2^{-23} 2^{-24} 2^{-25} 2^{-26} 2^{-27} 2^{-28}

The bit weights for a single-precision word are the same as those given for most sig. above.

The actual downlink formats are organized into 100-word lists. Each list, therefore, requires 2 sec to complete on the high bit rate. The general format for AGC downlink lists is given in Fig. 3.3. The seven phases referred to correspond to phases of the downlink program for Mission 202. For Flight 202 there are only two lists, the non-update list, which is transmitted throughout the flight except for the period of time between the initiation of a V76 update (see sec. 3.3) and the beginning of major mode 23, and the update list, which is transmitted during the period mentioned above. A computer restart while transmitting the update list may cause a premature return to the non-update list. With the exception of restarts, the list switches are only made in phase 1 and, therefore, the switchover occurs only after the list has been completely cycled through. If no V76 update is attempted, the update list will never be transmitted during Flight 202.

Marker words are used to identify when updating of certain data words has been accomplished. When a marker word is sent, bit 9 of OUT 1 = 1, causing the word order code bits to be 1's. Marker words will not be transmitted during phases 1, 2, or 5.

There is a cell in the AGC's erasable memory called "TMMARKER". In phases 3 and 6, this cell is checked before a word is telemetered. If it is zero, then the normal word is sent. If it is non-zero, the contents of TMMARKER are added to 74000_8, (making bits 15 through 12 1's), bit 9 of OUT 1=1, and the quantity is placed in the telemetry output register of the computer (register OUT 4). The marker counter is decreased by 1. The setting of bit 9 of OUT 1-1 causes the word order code to be a 1: if data words are transmitted, this bit is set to 0. "TMMARKER" is set to zero after being sampled.

In phases 4 and 7, the process in the previous paragraph is performed unconditionally (i.e., regardless of whether the contents of TMMARKER are zero or not). Whenever a marker word is sent, the "marker count" is reduced by 1; since it is preset to 3 at the start of phase 3 and phase 6, the proper synchronism of output words is maintained. When the counter reaches zero, phase 4 (or 7) is terminated. If the contents of TMMARKER are zero, the terminology "dummy marker" is employed: note that it is not necessarily true that only dummy markers are sent in phase 4 and phase 7. In phase 3 and 6, the counter is not less than 0.

Only the least significant three bits of TMMARKER are set in the program. Bit 1 (called "Marker 1") is set to 1 after the PIP registers have been sampled and a new value for PIPTIME loaded. This action affects words 29-31 and words 78-79 of the non-update list. Marker 1 will be generated each 0.5 second before GRR is sensed, each 2.0 seconds between GRR and about 10.5 seconds after SPS1 cutoff, each 2.0 seconds between SPS2-30 seconds and splash, and each 2.5 seconds if an abort is encountered (reverting to 2.0 seconds when entry computations are started).

Phase No.	Word No.	Contents
1	1	ID WORD
2	2 ... 15	DSPTAB
	16 .. 27	COMMON GROUP
3	28 .. (48 + K)	PART A & K MARKERS
4	(49 + K) ... 51	DUMMY MARKERS OR ACTUAL MARKERS
5	52 ... 65	DSPTAB
6	66 ... (97 + J)	PART B & J MARKERS
7	(98 + J) ... 100	DUMMY MARKERS OR ACTUAL MARKERS

Fig. 3. 3 General AGC Downlink Format

Bit 2 (called "Marker 2") is set after position and velocity have been updated in the navigation computations. This action affects words 66-77 of the non-update list. Marker 2 will be generated each 2.0 seconds between GRR and the end of the local vertical phase, and each 2.0 seconds between SPS2-28 seconds and splash. It will be generated each 2.5 seconds if an abort is encountered (reverting to 2.0 seconds when entry computations are started). Interrupts are inhibited by the program from affecting words 66-77 while they are being updated and Marker 2 generated (a similar statement applies to the other two markers). The events flagged by Marker 1 and Marker 2 occur fairly close together in the program. The Navigation computations are employed to assist in maintaining local vertical (hence Marker 2 lasts longer than Marker 1 after SPS1 cutoff).

Bit 3 (called "Marker 3") is set after the desired value(s) of the CDU angles have been determined. This action affects words 32-34 of the non-update list. It is set at the normal computation cycle rate of once per 2 seconds for entry and once per 2.5 seconds for abort. During entry, it is related to word 32 of the non-update list (words 33 and 34 are also changing, but are not flagged by Marker 3).

The contents of TMMARKER are modified independently by these three bits; consequently, more than one of the three might be 1 for the same downlink word. It is reset only when being sampled for downlink transmission. So, if a Marker takes place during a telemetry phase when no markers are being sent, it will be sent at the next marker opportunity.

A list of the non-update format is given below. Word numbers which are followed by asterisks indicate the word may shift position due to marker words as explained in the preceeding paragraph. The "octal cell" column gives the actual address of the erasable register in the AGC.

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
Pase 1				In this phase the check is made of whether the "normal" or the "uplink" list is to be sent and a cell set with the proper quantity accordingly.
1	1		ID WORD	ID word equals 110010000110111 1. Bit 9 of OUT1=1(Causes word order code to be 1's) ID different for uplink list. Least significant 11 bits are corresponding bits of "starting address" of non-uplink list (address of cell specifying final word to be sent).
Phase 2				In this phase "common List A" is sent, consisting of 26 words. No markers are sent.
0	2	0710	DSPTAB+0	Display
0	3	0711	DSPTAB+1	Display
0	4	0712	DSPTAB+2	Display
0	5	0713	DSPTAB+3	Display
0	6	0714	DSPTAB+4	Display
0	7	0715	DSPTAB+5	Display
0	8	0716	DSPTAB+6	Display
0	9	0717	DSPTAB+7	Display
0	10	0720	DSPTAB+8D	Display
0	11	0721	DSPTAB+9B	Display
0	12	0722	DSPTAB+10D	Display
0	13	0723	DSPTAB+11D	Moding relays in DSKY
0	14	0724	DSPTAB+12D	Moding relays in DSKY
0	15	0725	DSPTAB+13D	MCP relays
0	16	0035	Time 2(most sig. bits)	AGC Clock Register

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	17	0036	time 1 (least sig. Bits)	AGC Clock Register
0	18	0004	IN 0	An input register
0	19	0006	IN 2	An input register
0	20	0007	IN 3	An input register
0	21	0011	OUT 1	An output register
0	22	0645	STATE	15 bits individually assigned meanings as flags, give information on state programs.

W.O.C.	WD/NO.	Octal Cell	DATA WORD	REMARKS
0	23	0646	FLAGWRD 1	15 bits individually assigned meanings as flags, give information on state of programs
0	24	0647	FLAGWRD 2	" " " " "
0	25	0047	CDU X	Register gives actual X CDU angle
0	26	0050	CDU Y	Register gives actual Y CDU angle
0	27	0051	CDU Z	Register gives actual Z CDU angle
Phase 3				In this phase "particular list A" is sent, consisting of 21 words. In addition, markers words will be sent if indicated, and a marker word takes precedence over data. A "marker counter" is set to 3 at the start of this phase and decremented whenever a marker word is sent; in Phase 4 marker "Dummy" words are sent until the counter is decremented to 0.
0	28*	1075	REDO CNTR	REDOCNTR: a counter counting the number of restarts performed by the computer(a restart is caused by various difficulties such as a one-step loop, a power transient, a parity failure, etc.)
0	29*	1001	DELV X	DELV X component of velocity increment. May be identical to X PIP sample if bias and scale factor correction small (amounting to less than one count), or if telemetered at the appropriate (small) time interval.

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	30*	1003	DELV Y	DELVY, Y component of velocity increment. Similar comments to word 29.
0	31*	1005	DELV Z	DELVZ Z component of velocity increment. Similar comments to word 29.

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	32*	0700	THETAD +0	AGC register which gives desired CDU X angle
0	33*	0701	THETAD + 1	AGC register which gives desired CDU Y angle
0	34*	0702	THETAD + 2	AGC register which gives desired CDU Z angle
0	35*	1100	RRECT+0 (most sig. bits of Xpos)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	36*	1101	RRECT+1 (least sig.bits of X pos.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	37*	1102	RRECT+2(most sig.bits of Y pos.)	SPS1 tailoff state vector component to be used in orbital integration program this register is time shared.
0	38*	1103	RRECT+3(least sig. bits of Y pos.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	39*	1104	RRECT+4(most sig. bits of Z pos.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	40*	1105	RRECT+5(least sig. bits of Z pos.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	41*	1106	VRECT+0(most sig. bits of X vel).	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	42*	1107	VRECT+1(least sig. bits of X Vel.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	43*	1110	VRECT+2(most sig. bits of Y vel.)	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	44*	1111	VRECT+3(least sig. bits of Y vel.)	SPS1 tailoff state vector component to be used in orbital integration program,this register is time shared.
0	45*	1112	VRECT+4(most sig. bits of Z vel).	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	46*	1113	VRECT+5(least sig. bits of Z vel).	SPS1 tailoff state vector component to be used in orbital integration program, this register is time shared.
0	47*	1456	T_{FF} (most sig. sig. bits)	Time of free-fall
0	48*	1457	T_{FF} +1(least sig, bits)	Time of free-fall
Phase 4				In this phase the "marker counter" is checked (it was set in Phase 3 start) and "Dummy" markers equal to the present value of the marker counter(in number) are sent. If 3 different marker words were sent in Phase 3, nothing is sent in Phase 4; if no markers words were sent in Phase 3, three "Dummy" markers words are sent in Phase 4 etc.
1	49*		TM MARKER	Dummy markers if actual markers have not occurred above.
1	50*		TM MARKER	Dummy markers if actual markers have not occurred above.
1	51*		TM MARKER	Dummy markers if acutal markers have not occurred above.
				In this phase "common list B" is sent, consisting of 14 words.

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
Phase 5				
				No markers are sent. Because of Phase 4, the "word number" is valid.
0	52	0710	DSPTAB+0	Displays
0	53	0711	DSPTAB+1	Displays
0	54	0712	DSPTAB+2	Displays
0	55	0713	DSPTAB+3	Displays
0	56	0714	DSPTAB+4	Displays
0	57	0715	DSPTAB+5	Displays
0	58	0716	DSPTAB+6	Displays
0	59	0717	DSPTAB+7	Displays
0	60	0720	DSPTAB+8D	Displays
0	61	0721	DSPTAB+9D	Displays
0	62	0722	DSTAB+10D	Displays
0	63	0723	DSTAB+11D	Moding relays in DSKY
0	64	0724	DSTAB+12D	Moding relays in DSKY
0	65	0725	DSPTAB+13D	MCP relays
Phase 6				In this phase "particular list B" is sent, consisting of 32 words In addition, marker words will be sent (see discussion under Phase 3). The "marker counter" is set to 3 at the start of this phase.
0	66 *	0765	R_N+0(most sig. bits)	Output of average G routine
0	67*	0766	R_N+1 (least sig. bits)	Output of average G routine

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	68*	0767	R_N+2 (most sig. bits)	Output of average G routine
0	69*	0770	R_N+3 (least sig. bits)	Output of average G routine
0	70*	0771	R_N+4 (least sig. bits	Output of average G routine
0	71*	0772	R_N+5 (least sig. bits)	Output of average G routine
0	72*	0773	V_N+0 (most sig. bits)	Output of average G routine
0	73*	0774	V_N+1 (least sig. bits)	Output of average G routine
0	74*	0775	V_N+2 (most sig. bits)	Output of average G routine
0	75*	0776	V_N+3 (least sig. bits)	Output of average G routine
0	76*	0777	V_N+4 (most sig. bits)	Output of average G routine
0	77*	1000	V_N+5 (least sig. bits)	Output of average G routine
0	78*	1464	PIPTIME (most sig. bits)	Time that the PIP registers are read and therfore the time corresponding to position and velocity above during average G task and time for VRECT and RRECT after they are frozen
0	79*	1465	PIPTIME +1 (least sig. bits)	
0	80*	1466	TIME 2 GR (most sig. bits)	2 registers which contain the time of guid. ref, release these registers are time shared
0	81*	1467	TIME 2 GR+1 (least sig. bits)	

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	82*	1462	TCUTOFF (most sig. bits)	2 registers which contain the time of lift-off, or time of engine on or off, depending on which was last to occur
0	83*	1463	TCUTOFF+1 (least sig. bits)	
0	84*	1214	RAVEGON +0 (most sig. bits of X pos.)	Position from orbital integration program to be used for SPS2 burn this register is time shared.
0	85*	1215	RAVEGON+1 (least sig. bits of X pos.)	Position from orbital integration program to be used for SPS2 burn this register is time shared.
0	86*	1216	RAVEGON+2 (most sig. bits of Y pos.)	Position from orbital integration program to be used for SPS2 burn this register is time shared.
0	87*	1217	RAVEGON+3 (Least sig. bits of Y pos.)	Position from orbital integration program to be used for SPS2 burn this register is time shared.
0	88*	1220	RAVEGON+4 (most sig. bits of Z pos.)	Position from orbital integraion program to be used for SPS2 burn this register is time shared.
0	89*	1221	RAVEGON+5 (least sig. bits of Z pos.)	Position from orbital integration program to be used for SPS2 burn this register is time shared.
0	90*	1222	VAVEGON+0 (most sig. bits of X Vel.)	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.
0	91*	1223	VAVEGON+1 (least sig. bits of X vel).	Velocity from orbital integratiom program to be used for SPS2 burn this register is time shared.
0	92*	1224	VAVEGON+2 (most sig. bits of Y vel.)	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	93*	1225	VAVEGON+3 (least sig. bits of Y vel.)	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.
0	94*	1226	VAVEGON+4 (most sig. bits of Z vel).	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.
0	95*	1227	VAVEGON+5 (least sig. bits of Z vel).	Velocity from orbital integration program to be used for SPS2 burn this register is time shared.
0	96*	1210	TAVEGON (most sig. bits)	Time that average G program will be activated for SPS2 burn this register is time shared.#
0	97*	1211	TAVEGON+1 (least sig. bits)	Time that average G program will be activated for SPS2 burn this register is time shared.#
Phase 7				In this phase the "marker counter" is checked (it was set in Phase 6 start), and "Dummy " marker words equal in number to the present value of the marker counter are sent (see discussion under Phase 4.
1	98*		TM MARKER	Dummy markers if actual markers have not occurred above
1	99*		TM MARKER	Dummy markers if actual markers have not occured above.
1	100*		TM MARKER	Dummy markers if actual markers have not occurred above.

Note TAVEGON is a ΔT measured relative to PIPTIME, therefore the absolute SPS2 average G on time = TAVEGON + PIPTIME.

For the update list only phases 1,3 and 6 are changed. The word number in phases 3 and 6 have no asterixes since none of the programs that generate markers are active during this phase of the flight. Phases 4 and 7 will contain 3 dummy marker words each. The update list will be entered after the proper intiation of a V76 update and will be transmitted until the initiation of major mode 23 (barring restarts). The switch over from one list to another occurs only in phase 1. The downlink words in phases 1, 3 and 6 are listed below.

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
Phase 1				
1	1	-----	ID WORD	ID word equals 1100100000000011. Bit 9 of OUT1=1 (causes word order code to be 1's) see comments under Phase 1 of non-update list.
Phase 3				In this phase "particular list A" (up-link format) is sent. As discussed above, no markers are sent, but since the "marker counter" is set to 3 at the start of phase 3, 3 dummy markers will be sent in phase 4, a total of 21 words are sent.
0	28	1100	STBUFF+0	1st component of V76 update, cell used for other purposes before V76 and therefore will have some initial value.
0	29	1101	STBUFF+1	2nd component of V76 update cell used for other purposes before V76 and therefore will have some initial value.
0	30	1102	STBUFF+2	3rd component of V76 update cell used for other purposes before V76 and therefore will have some initial value.
0	31	1103	STBUFF+3	4th component of V76 update cell used for other purposes before V76 and therefore will have some initial value.
0	32	1104	STBUFF+4	5th component of V76 update cell used for other purposes before V76 and therefore will have some initial value.
0	33	1105	STBUFF+5	6th component of V76 update cell used for other purposes before V76 and therefore will have some initial value.

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	34	1106	STBUFF+6	7th component of V76 update, cell used for other purposes before V76 & will have some initial value.
0	35	1107	STBUFF+7	8th component of V76 update cell used for other purposes before V76 & will have some initial value.
0	36	1110	STBUFF+8D	9th component of V76 update cell used for other purposes before V76 & will have some initial value.
0	37	1111	STBUFF+9D	10th component of V76 update cell used for other purposes before V76 & will have some initial value.
0	38	1112	STBUFF+10D	11th component of V76 update cell used for other purposes before V76 & will have some initial value.
0	39	1113	STBUFF+11D	12th component of V76 update cell used for other purposes before V76 & will have some initial value.
0	40	1114	STBUFF+12D	13th component of V76 update cell used for other purposes before V76 & will have some initial value.
0	41	1115	STBUFF+13D	14th component of V76 update cell used for other purposes before V76 & will have some initial value.
0	42		SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011
0	43		SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011.
0	44		SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011.
0	45		SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011.
0	46		SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011.

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	47		SPARE	Contents of 1st 16 bits have set pattern of 1010101010101011.
0	48	1123	STCNTR	Indicates which component of V76 update is presently being loaded.
Phase 6				In this phase "particular list B" (uplink format) is sent. As discussed above, no marker words are sent, but since the "marker counter" is set to 3 at the start of this phase, 3 "Dummy" marker words will be sent in Phase 7. A total of 32 words are sent.
0	66	1466	TIME 2 GR	Same comment as on preceding list, will not be GRR time at this point.
0	67	1467	TIME 1 GR	
0	68	1462	TCUTOFF	Same comment as on preceding list, will be SPS1 cutoff time at this point in flight
0	69	1463	TCUTOFF+1	
0	70	1214	RAVEGON+0	Same comment as on preceding list
0	71	1215	RAVEGON+1	Same comment as on preceding list
0	72	1216	RAVEGON+2	Same comment as on preceding list
0	73	1217	RAVEGON+3	Same comment as on preceding list
0	74	1220	RAVEGON+4	Same comment as on preceding list
0	75	1221	RAVEGON+5	Same comment as on preceding list
0	76	1222	VAVEGON+0	Same comment as on preceding list
0	77	1223	VAVEGON+1	Same comment as on preceding list
0	78	1224	VAVEGON+2	Same comment as on preceding list
0	79	1225	VAVEGON+3	Same comment as on preceding list
0	80	1226	VAVEGON+4	Same comment as on preceding list
0	81	1227	VAVEGON+5	Same comment as on preceding list

W.O.C.	WD/NO.	OCTAL CELL	DATA WORD	REMARKS
0	82	1210	TAVEGON	Same comment as on preceding list
0	83	1211	TAVEGON+1	Same comment as on preceding list
0	84	1100	STBUFF+0	1st component of V76 update
0	85	1101	STBUFF+1	2nd component of V76 update
0	86	1102	STBUFF+2	3rd component of V76 update
0	87	1103	STBUFF+3	4th component of V76 update
0	88	1104	STBUFF+4	5th component of V76 update
0	89	1105	STBUFF+5	6th component of V76 update
0	90	1106	STBUFF+6	7th component of V76 update
0	91	1107	STBUFF+7	8th component of V76 update
0	92	1110	STBUFF+8D	9th component of V76 update
0	93	1111	STBUFF+9D	10th component of V76 update
0	94	1112	STBUFF+10D	11th component of V76 update
0	95	1113	STBUFF+11D	12th component of V76 update
0	96	1114	STBUFF+12D	13th component of V76 update
0	97	1115	STBUFF+13D	14th component of V76 update

The following paragraphs describe the contents of the various cells which are telemetered. For convenience in presentation, they are arranged in sequence of the octal cell numbers given; also included are the word numbers of the cell in question: a single number means that the quantity is present at the same word number for both non-update and update formats, while a slash ("/") is used to separate non-update word numbers (to the left of the slash) from update word numbers.

It should be emphasized that many of the quantities that are telemetered on the downlink are actual quantities that are in use for performing computations. Although labeled with certain meanings, the various flags (and, to some extent, variables) can on occasion have specialized meanings or settings not implied by their isolated definitions. For example, when entry preparations are commenced and no abort burn has taken place, the bit is set that is labeled "SPS4 burn", even though (for e.g. separation without an abort signal at LET jettison) not even a single (SPS1) burn of the SPS engine has taken place.

Octal Cell	Word #	Discussion
0004	18	Hardware input register "IN0". Individual bits (bit 15, as usual, is sign bit and bit 1 the least significant magnitude bit) have following meanings.

Bits	Meaning
1-5	Input from astronaut keyboard (not uplink), having patterns as shown on page 3-15 for the right-most group of five bits. If a zero is entered, for example, bit 5 would be 1 and bits 4-0 equal to 0.
6	"accept uplink"
7	"inhibit upsync"
8-14	"spare"
15	If 1, indicates a "mark" (used in conjunction with optics).

Octal Cell	Word #	Discussion
0006	19	Hardware input register "IN2". Individual bits assigned following meanings (see discussion of cell 0004 for other general comments).

Bits	Meaning
1-4	high-speed timing inputs (bit 1 is 1600 pps; bit 2, 800 pps, bit 3, 400 pps, bit 4, 200 pps).
5	Liftoff signal normally received (not set if uplink lift-off sent).
6	Guidance Reference Release signal normally received (computer software, not hardware, causes liftoff to be a backup to this signal).

Bits	Meaning
7	"Saturn Ullage"
8	SIVB Separation signal.
9	"SM/CM Separate"
10-12	CDU fail, PIPA fail, and IMU fail, repectively.
13-14	"spare"
15	"parity"

Octal Cell	Word #		
0007	20	Hardware input register "IN3". Individual bits assigned the following meanings.	
		1-4	"K1" - "K4" respectively
		5	"K12"
		6	"trn. sw."
		7	"K5"
		8-9	"spare"
		10	"opt. mode SW3"
		11	"star present"
		12	"zero optics"
		13	"sextant on"
		14	"opt. mode SW2"
		15	"0R of C1-C33"
0011	21	Hardware output register "OUT1". Individual bits assigned the following meanings (same general comments as on provious registers)	
		1	Program alarm (e.g. Delta-V and V_g alarms, as well as others).
		2	"computer activity"
		3	Key release light, associated with keyboard or uplink activity.
		4	Fail light, set if ($C\bar{C}C$) failure in uplink, or if too many or not enough end pulses are received from the telemetry system.
		5	Program check fail light, set if a VERB 75 command is received at an "improper" time, if some illegal uplink information is sent provided that it passes the ($C\bar{C}C$) checks, etc.

Octal Cell	Word #	Bits	Meaning
		6	"spare"
		7	"rupt trap reset"
		8	"spare"
		9	Used to specify the word order code for telemetered words. Should be 0 whenever OUT1 information is sent on the downlink.
		10	Bit set to 1 if too many telemetry end pulses are received from the NAA telemetry programmer (i.e. more than 7 in a 120-millisecond interval, with the interval controlled by a "T4RUPT" program). Is used to keep the telemetry system (which nominally sends one word each 20 milliseconds) from tying up the AGC in the event of a malfunction (inhibits pulses and therefore the AGC downlink will have all zeros).
		11-12	"spare"
		13	SPS engine on
		14-15	"spare"

NOTE: When an "error reset" signal is sent, bits 1, 4, 5, 7, and 10 of OUT1 are set to zero.

		Discussion
0035-0036	16-17	AGC clock register, scaled B28 centi-seconds (double precision number with most significant part in cell 0035). Incremented by 1 each 10 ms. This register is sampled when the program needs to find out "what time it is" (for such applications as liftoff and cutoff time storage).
0047-0051	25-27	Registers containing actual CDU X, Y, Z angles respectively, in two's complement scaled B-1 revolutions: 00000 is 0^o, 40000 is 180^o. When being driven under program control, they are changed cyclically (X, Y, Z, X, . . .), with the next one in sequence driven each 60 ms (a given one is driven each 180 ms) by a "T4RUPT" program and making use of hardware output register OUT2 (not telemetered).

NOTE: The remaining cells are in the computer erasable memory. No attempt has been made to identify their contents before GRR (Guidance Reference Release): they are, in some cases, used for prelaunch programs during this time. Similarly, in virtually all cases their contents prior to the initial loading specified below will <u>not</u>, in general, be zero.

0645	22	A computer word identified as "STATE" which, in conjunction with words #23 and #24, contain virtually all of the flags used in the computations control logic. In the prelaunch initial conditions program (conducted well before GRR) this word is set to 01360_8 (i.e. bits 5-8 and 10 are set to 1).

Octal Cell	Word #	Bits	Meaning
		1	"PRGSW", a control bit used in conjunction with the detailed scheduling of different computer jobs(in an "Executive Interlock Routine.")
		2	"UPLOCK": set to 1 if an uplink (C$\bar{C}$C) check fails. Program ignores everything but an "error reset" signal if this bit is 1: the error reset causes the bit to be reset to zero. Note that other uplink signals (such as the VERB 75 ones for backup liftoff, etc.) could bring about the setting of this bit, as well as VERB 76 state vector updates. Bit 4 of OUT1 (if timing considerations associated with sampling are ignored) will be 1 if bit 2 of STATE = 1 (the converse is not true because of other uses for bit 4 of OUT1.)
		3	"EXTVBACT": set to 1 if one of several "extended verbs" have activity (such as various verbs to control the IMU). The "verb" comes from the astronaut key-board or the uplink. Bit used to prevent more than one verb from being acted upon at the same time.
		4	"DSPLOCK": set to 1 if the "display system is locked": used to avoid problems that could arise if, for example, keyboard and uplink commands were being issued, or some other problem, such as conflicts between key-board and subroutine calls.
		5	"LATSW": Switch in entry computations: binary bit is 1 if switch has "logical" (i.e. equation) value of 0: bit one of several preset to 1 in initial conditions routine (see above).
		6	"HIND2SW": Switch in entry computations. Binary bit is 1 if switch has 1 ogical value of 0.
		7	"HUNTSW1": Switch in entry computations. Binary bit is 1 if switch has logical value of 0.
		8	"EGSW": Switch in entry computations. Binary bit is 1 if switch has logical value of 0.
		9	"RELVELSW": Switch in entry computations. Binary bit is 0 if switch has logical value of 0 (i.e. the "usual" arrangement).
		10	"GONEPAST": Switch in entry computations. Binary bit is 1 if switch has logical value of 0.
		11	"NBSMBIT": Used in "inflight alignment subroutines". If 1, rotation from Navigation Base to Stable Member performed; if 0, the reverse (used to control axis rotation routine). It is set to 1 after GRR is sensed.
		12	"FIRSTFLG": Denotes "first incorporation for IMU-Landmark measurement".

Octal Cell	Word #	Bits	Meaning
		13	"MOONFLAG": Denotes computation near moon (used to control orbital integration program, e.g. whether oblateness computation is performed). Should be 0 for 202.
		14	"MIDFLAG": Controls orbital integration program logic. Should be 0 for 202.
		15	"JSWITCH": Controls orbital integration program logic ("0 for state vector, 1 for W matrix"). Should be 0 for 202.

Discussion

0646 23 A computer word identified as "FLAGWRD1" used, with words #22 and #24, to control the computational logic. In the prelaunch initial conditions program, this word is set to 00000.

Bits	Meaning
1	"TUMBFLAG": set to 1 if tumble state detected.
2	"LIFTFLAG": Symbol not referenced by T4RUPT. Bit set to 1 when lift off has been sensed.
3	"ENTRYFLG": Set to 1 after post CM/SM maneuver has been completed.
4	"STEERFLG": Set to 1 to permit steering.
5	"DVMONFLG": Set to 1 to enable ΔV monitor (checks that getting thrust from engines).
6	"MONITFLG": Set to 1 for Saturn pitch monitor.
7	"INTIFLAG": Set to 1 when T_{ff} first becomes less than 160 seconds (if free-fall interrupt enabled).
8	"S4BSMFLG": Set to 1 when S4B/SM separation sensed.
9	"INITFLAG": Indicates initial computations.
10	"INTPFLAG": Free-fall interrupt enabled.
11	"ACTIVFLG": Control flag for IMUSTALL program which insures that no two programs use IMUSTALL at the same time.
12	"SHTDNFLG": Entry preparations (based on T_{ff} or some other reason, such as a ΔV alarm) started.
13	"VERTFLAG": Local vertical phase.
14	"UPDATFLG": Set to 1 if successful update completely received, reset to 0 if another VERB 76 ENTER sequence received. Updating information ignored unless bit is 1. Bit set to 0 two seconds before +X associated with SPS2 (in the event that orbital integration has not yet halted).
15	"COASTFLG": In coast phase.

Octal Cell	Word #	Bits	Meaning	Discussion
0647	24	A computer word identified as "FLAGWRD2" used, with words #22 and #23, to control the computational logic. In the pre-launch initial conditions program, this word is set to 00000.		
		1	"ARRSTFLG": Tumble arrest burn.	
		2	"ABRTFLAG": Abort burn.	
		3	"TABTFLAG": Burn after tumble arrest.	
		4	"SPS1FLAG": Indicates burn for SPS1.	
		5	"SPS2FLAG": Indicates burn for SPS2.	
		6	"SPS3FLAG": Indicates burn for SPS3.	
		7	"SPS4FLAG": Indicates burn for SPS4 (or entry process even if SPS4 burn does not take place).	
		NOTE: As a rule, only one of the above bits would be 1 at any given time.		
		8-13	Flags associated with the performance of large attitude maneuvers (BEGINFLG, NEGFLAG, DOMANFLG, CALCFLAG, ROLLFLAG, and BACKFLAG, respectively).	
		14	"CDUXFLAG": Set to 1 when CDU X scale change made (about 5 seconds before separation of CM and SM).	
		15	"DRIFTFLAG": Enables free-fall gyro bias compensation.	

Octal Cell	Word#	Discussion
0700-0702	32-34/--	Cells containing desired CDU angles, same format as actual CDU angles (see discussion of cells 0047-0051). Marker 3 is used in several instances to identify when this group of cells has been changed, but in a number of instances this use is incomplete (see comments in list).
0710-0725	2-15 & 52-65	DSPTAB words.

DSPTAB+0 thru DSPTAB+10D — These 11 registers give the status of the DSKY displays, if bits 15 thru 12 are 0001, the next 11 bits will indicate actual status of DSKY displays; if bits 15 thru 12 are 1110 the next 11 bits indicate the complement of the status to which the AGC will command the DSKY display. The contents of these words are:

	Bit 11	Bits 10 thru 6	Bits 5 thru 1
DSPTAB+0	-R3S	R3D4	R3D5
DSPTAB+1	+R3S	R3D2	R3D3
DSPTAB+2		R2D3	R3D1
DSPTAB+3	-R2S	R2D3	R2D4
DSPTAB+4	+R2S	R2D1	R2D2
DSPTAB+5	-R1S	R1D4	R1D5
DSPTAB+6	+R1S	R1D2	R1D3
DSPTAB+7	UPACT		
DSPTAB+8D		ND1	ND2
DSPTAB+9D	FLASH	VD1	VD2
DSPTAB+10D		MD1	MD2

where R3D2 stands for digit two of the third register and ND1 stands for digit one of the noun display, etc.

Where D1 is the leftmost digit or the most significant digit in the display, the actual codes for the digits are shown below.

For the right character of a pair, the MSB is placed in bit 5; the LSB is bit 1. For the left character of a pair, the MSB is placed in bit 10; the LSB, in bit 6.

	MSB LSB
Blank	0 0 0 0 0
0	1 0 1 0 1
1	0 0 0 1 1
2	1 1 0 0 1
3	1 1 0 1 1

	MSB LSB
4	0 1 1 1 1
5	1 1 1 1 0
6	1 1 1 0 0
7	1 0 0 1 1
8	1 1 1 0 1
9	1 1 1 1 1

As shown above bit 11 of some of the DSPTAB registers contain additional discrete information. If a one appears in bit 11, it indicates that the discrete is on. For example, a one in bit 11 of DSPTAB+1 indicates that R3 has a plus sign[1] while a one in bit 11 of DSPTAB+9D indicates that the displays are flashing.

A diagram of the DSKY face to show the positions of the different digits follows:

program
MD1 MD2

verb
VD1 VD2

noun
ND1 ND2

register 1

± R_1D_1 R_1D_2 R_1D_1 R_1D_4 R_1D_5

register 2

± R_2D_1 R_2D_2 R_2D_3 R_2D_4 R_2D_5

register 3

± R_3D_1 R_3D_2 R_3D_3 R_3D_4 R_3D_5

DSPTAB+11D to DSPTAB+13D - These registers have information on the G&N and MCP moding relays and warning lights on the DSKY, if bits 15 thru 12 are 1000 the AGC has not yet commanded the relays to the new state, if bits 15 thru 12 are 0000 the last eleven bits indicate the state of the relays. Bits 11 thru 1 of these words contain eleven discretes with a one indicating that the discrete is "on". DSPTAB+12D contains mostly spares with the exception of a couple of optics switches and therefore is of no interest for flight 202. The discretes for each bit position is DSPTAB+11D and DSPTAB+13D are as follows:

[1] A plus or minus sign in any register indicates that the contents of that register is decimal rather than octal.

		DSPTAB+11D	DSPTAB+13D
bit	1	zero encode	G&N att. control select
	2	coarse align	G&N ΔV select
	3	lock CDU	G&N entry select
	4	fine align	CM/SM sep. command
	5	encoder zero lamps	+X trans.
	6	CDU fail lamp	spare
	7	PIPA fail lamp	auto .05 ind.
	8	IMU fail lamp	gim. mot. pwr. cont.
	9	spare	FDAI align
	10	attitude control	telecom switch
	11	roll reentry	backup abort command

Octal Cell	Word #	Discussion
0765-0772	66-71/--	These cells contain double-precision quantities related to the vehicle position vector (X, Y, Z respectively) with a scale factor of B24 and with units of meters. As part of the prelaunch erasable memory load, these cells are loaded with an initial value of the position vector. About 2 seconds after the GRR signal is sensed, these cells will be modified by the navigation computations (as flagged by Marker 2). This modification will continue (at the computation cycle rate) until the end of the local vertical phase (controlled by an E-memory quantity, but presently about 2037 seconds from SPS1 cutoff). These cells will then contain (while presets are being made for SPS2) the orbital-integration value of $\underline{R}$ at 4 seconds before ignition, then its value at ignition, and finally its value at "Average-G on" (30 seconds before +X). The intermediate values will remain for only a short time, and hence may not be telemetered. The value at "Average-G on" is obtained from cells 1214-1221 (discussed below). If no update is performed, the value at "Average-G on" will remain until about 28 seconds before SPS2 ignition, when navigation computations (as flagged by Marker 2) are resumed and continued until flight termination. If an update is successfully received, these cells will be loaded with the revised "Average-G on" value obtained from orbital integration from the updating information (cells 1214-1221) shortly after SPS2 -50 seconds. They will retain this value until navigation computations are resumed at SPS2 -28 seconds approximately.
0773-1000	72-77/--	These cells contain double-precision quantities related to the vehicle velocity vector (X, Y, and Z respectively) with a scale factor of B7 and with units of meters/centi-second. A centi-second is 0.01 second. Their history is similar to that of cells 0765-0772. When GRR is sensed, these cells are loaded with the vector cross product of a unit polar vector times $\underline{R}$, multiplied by earth rate. About 2 seconds after the GRR signal is sensed,

Octal Cell	Word #	Discussion
		these cells will be modified by the navigation computations (as flagged by Marker 2), and the navigation computations continue to be solved until the end of the local vertical phase. These cells will then contain briefly the orbital-integration value of $\underline{V}$ at ignition, and will then be loaded with the orbital-integration value of $\underline{V}$ at "Average-G on". This value is obtained from cells 1222-1227. As was true for cells 0765-0772, the intermediate value of $\underline{V}$ may not be telemetered. If no update is performed, the "Average-G on" value will remain until about 28 seconds before SPS2 ignition, when navigation computations (as flagged by Marker 2) are resumed and continued until flight termination. If an update is successfully received, these cells will be loaded with the revised "Average-G on" value obtained from orbital integration from the updating information (cells 1222-1227) shortly after SPS2 -50 seconds, with navigation resumed about SPS2 -28 seconds.
1001 1003 1005	29/-- 30/-- 31/--	These three cells contain single-precision velocity increments for X, Y, and Z respectively. They are loaded with the output of the accelerometer registers on a periodic computation-cycle basis, as flagged by Marker 1. They are then subject to accelerometer scale factor and bias correction processing and then used in navigation (at the completion of navigation, Marker 2 is set). If the accelerometer corrections exceed one count, then the value telemetered would be affected (the necessary correction constants are loaded as part of the prelaunch erasable-memory load). Before receipt of GRR, these cells are loaded each 0.5 second with the accelerometer count, and the scale factor and bias correction processing performed (hence several Marker 1 outputs would be encountered in the 100-word list). Starting after receipt and sensing of GRR, they are loaded at a 2-second rate (assuming no aborts), as flagged by Marker 1, until about 12.5 seconds after SPS1 cutoff. At this time, the cells are all set to 0 (to permit "free flight navigation" for local vertical phase). The cells remain at 0 until about SPS2 -30 seconds, when the PIP registers are sampled (flagged by Marker 1) to clear them. The resulting velocity "increments" accumulated during coast, of course, are not used in navigation. Two seconds later (SPS2 -28 seconds), the normal periodic sampling of the PIP registers, with corrections, is resumed and continued for the remainder of the flight.
1075	28/	REDOCNTR: Cell related to number of restarts performed, set to 0 as part of prelaunch erasable-memory presets. See discussion on page 3-21.
1100	35/28&84	Used for several purposes. Loaded about 10.5 seconds after SPS1 cutoff with most significant part of X component of position from navigation. After the end of the local vertical phase, it contains intermediate quantities of the orbital integration program. At the end of this process, the cell contains the most significant part of X component of position predicted to be valid at SPS2 ignition. With no update, it retains this value until entry. With an update, it contains the first update

Octal Cell	Word #	Discussion
		component (STBUFF+0) when received, until SPS2 ignition -50 seconds, when it again contains intermediate quantities of the orbital integration program, ending with the same value as cell 1214. This value is retained until entry.
		When the "Predict 3" phase of entry (major mode 67) is started, the cell will contain F3 (V), scaled nmi/2700.

NOTE: Cells 1101-1105 parallel 1100's history, containing different components of vectors (in the usual order), different update components, etc., prior to entry.

1101	36/29&85	See discussion of 1100 for contents before entry.
		When the "Predict 3" phase of entry is started, this cell will contain briefly the value of -DREFR (V), scaled $fps^2/805$. A value of 00000 will probably be telemetered, however, as the cell is set to zero before F3 (V) is used in the computations.
1102	37/30&86	See discussion of 1100 for contents before entry.
		When the "Predict 3" phase of entry is started, this cell will contain the value of RTOGO (V), scaled nmi/2700.
1103	38/31&87	See discussion of 1100 for contents before entry.
		When the "Predict 3" phase of entry is started, this cell will contain the value of RDOTREF (V), scaled $fps/(25766.1973 \times 2^{-2})$.
1104	39/32&88	See discussion of 1100 for contents before entry.
		When the "Predict 3" phase of entry is started, this cell will contain the value of -F2 (V), scaled $25766.1973/(2700 \times 4)$ with units of nmi/fps^2.
1105	40/33&89	See discussion of 1100 for contents before entry.
		When the "Predict 3" phase of entry is started, this cell will contain the value of F1 (V), scaled (2700/805) with units of nmi/fps^2.
1106	41/34&90	Used for several purposes (analogously to cell 1100).
		Loaded about 10.5 seconds after SPS1 cutoff with most significant part of X component of velocity from navigation. After the end of the local vertical phase, it contains intermediate quantities of the orbital integration program. At the end of this process, the cell contains the most significant part of X component of velocity predicted to be valid at ignition (of SPS2). With no update, it retains this value until entry. With an update, it contains the seventh component (STBUFF+6) when received, until SPS2 ignition -50 seconds, when it again contains intermediate quantities of the orbital integration program, ending with the same value as cell 1222. This value is retained until entry.
		When the "Predict 3" phase of entry is started, the cell will contain the value of PREDANGL, scaled B-3 in units of earth revolutions (one revolution is 21,600 nmi).

NOTE: Cells 1107-1113 parallel 1106's history, containing different components of vectors (in the usual order), different update components, etc., prior to entry.

Octal Cell	Word #	Discussion
1107	42/35&91	See discussion of 1106 for contents before entry. When the "Predict 3" phase of entry is started, this cell will contain the value of the indexing parameter used to select the proper table entry on page 5-37 (R-477, Rev. 3), scaled B14. It is preset to 14 and counted down until the appropriate entry is identified (hence an intermediate value might be telemetered). Numbering the entries from 0 at the top of the page, it is equal to the first entry for which the reference velocity minus the vehicle velocity is less than or equal to 0 (examining the table from the bottom of the page). For example, if V = 1500 fps, word 42 would be 00002.
1110	43/36&92	See discussion of 1106 for contents before entry. When entry computations are started (shortly after completion of the maneuver to entry attitude following CM/SM separation), this cell contains the value of THETA (most significant part), scaled B0 revolutions, as defined at the bottom of page 5-27 of R-477, Rev. 3.
1111	44/37&93	See discussion of 1106 for contents before entry. During entry, contains the least significant portion of THETA (see cell 1110).
1112	45/38&94	See discussion of 1106 for contents before entry. During entry, contains the most significant part of the value of LATANG, scaled B2, as defined at the bottom of page 5-29 of R-477, Rev. 3.
1113	46/39&95	See discussion of 1106 for contents before entry. During entry, contains the least significant portion of LATANG (see cell 1112).
1114	--/40&96	The orbital integration performed at the end of local vertical leaves this cell with contents of zero. It is loaded with STBUFF+12, the 13th component of the state vector update. It retains this value until after it is no longer telemetered (the last time it is telemetered, it might, because of timing considerations, contain a result from the orbital integration program performed at SPS2 -50 seconds.
1115	--/41&97	Same as 114 (loaded with STBUFF+13, the 14th component of the state vector update).
1123	--/48	STCNTR, scaled B14. Set to 13_{10} (octal 00015) until first component of update (5 characters) is accepted, when it is decremented by 1. If cell STBUFF+n is being loaded, STCNTR = (13 - n). Once it has counted down to zero, it remains there (unless another VERB 76 ENTER sequence is received, when it would go back to 13_{10}).

Octal Cell	Word #	Discussion
1210-1211	96-97/ 82-83	About 10.5 seconds after SPS1 cutoff loaded with integration interval (time in B28 centi-seconds) required to perform orbital integration using the contents of cells 1100-1113. The time is measured as a time difference between the last PIPA sample used in Navigation (which gives the "effective sampling time" of of the Navigation output) and when SPS2 +X is to be initiated. $$T = 3133.67 - (T_{pip} - T_{co})$$ The orbital integration program may affect its contents. Shortly after SPS2 -50 seconds, the cell becomes the difference between (T_{co} + 3133.67) and the double-precision word stored by the update program in STBUFF+12 and STBUFF+13, provided of course an update was successfully completed. In this discussion, T_{co} is cutoff time of SPS1. During prelaunch operations (major mode less than 10_8), the five-bit astronaut's keyboard or "net" uplink message is stored in cell 1210 for telemetry purposes. The "net" message is the 5 least significant bits.
1214-1221	84-89/ 70-75	Used for several purposes. From shortly after liftoff +2 seconds until the end of the local vertical phase, these cells will contain the Atlantic unit target vector (sealed B1), rotated from GRR to liftoff, Shortly after this time, it will contain the value of the position vector (double precision B24 meters) predicted by the orbital integration program for the time of "Average-G on" (c.f. cells 0765-0772). If an update is received, shortly after SPS2 -50 seconds they will contain the value of the position vector predicted for "Average-G on" time based on the update information. During entry, the cells will contain the target vector, scaled B1.
1222-1223	90-91/ 76-77	Shortly after end of local vertical phase, this pair of cells will contain double-precision X component of velocity predicted by the orbital integration program for "Average-G on" time. If an update is received, it will contain this same quantity based on the uplink data, shortly after SPS2 -50 seconds. From shortly after completion of the maneuver to entry attitude until flight termination, this pair of cells will contain the value of "L/D" in the entry computations, scaled B0. At each engine off, the complement of the contents of the XPIP accumulation register is loaded into 1222 and YPIP into 1223.
1224-1225	92-93/ 78-79	Shortly after end of local vertical phase, this pair of cells will contain double-precision Y component of velocity, computed and updated analogously to cells 1222-1223. During entry, they will contain the value of DIFF scaled nmi/21600 $\times 2^4$. At each engine off, the complement of the contents of the ZPIP accumulation register is loaded into 1224.
1226-1227	94-95/ 80-81	Shortly after local vertical phase, this pair of cells will contain double-precision Z component of velocity computed and updated analogously to cells 1222-1223.

Octal Cell	Word #	Discussion
1456-1457	47-48/--	From shortly after GRR is sensed until shortly after SPS1 cutoff +10.5 seconds, this cell will contain the double-precision value of T_{ff}. Its value remains constant until the navigation computations cease when the maneuver to entry attitude (after CM/SM separation) has been completed, and the value then existing remains until flight termination. Note that the computation of this quantity involves a square root: if this involves an attempt to take the square root of a negative number (e.g. if the interface altitude is too high), T_{ff} is set zero.
1462-1463	82-83/ 68-69	This cell contains the value of the computer clock (c.f. cells 0035-0036) when liftoff was sensed, when an engine turn-on command was issued, or when an engine turn-off command was issued, whichever was the most recent to occur.
1464-	78-79/--	This cell contains the value of the computer clock (c.f. cells 0035-0036) when the PIPA registers were last sampled. Its change, together with that of cells 1001, 1003, and 1005, is flagged by Marker 1.
1466	80-81/	This cell contains the contents of cells 1464-1465 when the occurrence of the GRR signal has been deduced. In essence, therefore, it contains the value of the computer clock for which the initial-condition position vector is valid. These cells also are used for the storage of transfer addresses (1466 from a routine, 1467 the starting address of the routine to be performed) for jobs to be performed "more than 120 seconds in the future". Once such job is FDAI align, performed 289.5 seconds after SPS1 cutoff +10.5 seconds. Consequently, after (SPS1 cutoff +10.5 seconds) this pair of cells no longer contains GRR time. At the end of FDAI align, they will be set for SPS2 -50 seconds.

The scale factors of the words in the preceeding lists are as follows unless otherwise indicated in the preceeding discussion.

Position	meters/2^{24}
Time	c.s/s^{28}
Velocity	$\frac{\text{meters/c.s}}{2^7}$
Acceleration	$\frac{\text{meters/sec}}{59.904 \times 2^4}$

1 c.s. = .01 sec.

Therefore dividing position in meters by 2^{24} will give a fraction which will code into the correct double precision word if the bit weights given in the beginning of the section are used. The same procedure would be used for double precision time words, etc.

3.5 Analog Data Telemetry and Recording

3.5.1 Types

The inflight information from G&N is of three types: PCM telemetry of the AGC DIGITAL DOWNLINK (PCMD*), PCM telemetry of low bandwidth G&N measurement (PCM +, PCM, PCME*), and on-board recording of high bandwidth G&N measurements FQ-TR*. The first type, AGC DIGITAL DOWNLINK, is described in section 3.4. The last two types, although including information in discrete form, are considered to be analog data.

3.5.2 Authorization

The PCM telemetry of the low bandwidth measurements and the on-board recording of the high bandwidthmeasurements have been defined by NASA in (1) APOLLO CM/SM BLOCK I, OPERATIONAL BASELINE MASTER MEASUREMENT LIST No. 9 of 15 March 1965 and (2) APOLLO CM/SM BLOCK I R AND D BASELINE MASTER MEASUREMENT LIST No. 9 of 15 March 1965 and are as listed below.

3.5.3 PCM Telemetry

The G&N PCM telemetry measurements are all classified OPERATIONAL. *

Identification		Function	Type	Sample Rate/Sec.
CG0001	V	Computer Digital Data	PCMD	50 S/S (refer sec. 3.4)
CG1010	V	+120 VDC Pipa Supply	PCM	1
CG1101	V	-28 VDC Supply	PCM+	1
CG1110	V	2.5 VDC TM Bias	PCM+	1
CG1301	V	IMU 2V 3200 CPS Supply	PCM	1
CG1503	X	IMU +28 VDC Operate	PCME	10
CG1513	X	IMU +28 VDC Standby	PCME	10
CG1523	X	AGC +28 VDC	PCME	10
CG1533	X	OPTX +28 VDC	PCME	10
CG2001	V	X Pipa SG Output, in phase	PCM	10
CG2021	V	Y Pipa SG Output, in phase	PCM	10
CG2041	V	Z Pipa SG Output, in phase	PCM	10
CG2110	V	IGA Torque Motor Input	PCM	10
CG2112	V	IGA 1X Res Output, sine, in phase	PCM	10
CG2113	V	IGA 1X Res Output, cos, in phase	PCM	10
CG2117	V	IGA Servo Error, in phase	PCM	100
CG2140	V	MGA Torque Motor Input	PCM	10
CG2142	V	MGA 1X Resolver Output, sine, in phase	PCM	10

*See Definitions - Section 3.5.5.

Identification		Function	Type	Sample Rate/Sec.
CG2143	V	MGA 1X Resolver Output, cos, in phase	PCM	10
CG2147	V	MGA Servo Error in phase	PCM	100
CG2170	V	OGA Torque Motor Input	PCM	10
CG2172	V	OGA 1X Resolver Output, sine, in phase	PCM	10
CG2173	V	OGA 1X Resolver Output, cos, in phase	PCM	10
CG2177	V	OGA Servo Error, in phase	PCM	100
CG2206	V	IGA CDU 1X Resolver Error, in phase	PCM	10
CG2236	V	MGA CDU 1X Resolver Error, in phase	PCM	10
CG2264	V	OGA CDU 16X Resolver Error, in phase	PCM+	10
CG2266	V	OGA CDU 1X Resolver Error, in phase	PCM	10
CG2300	T	PIPA Temp.	PCM+	1
CG2301	T	IRIG Temp.	PCM+	1
CG2302	C	IMU Heater Current	PCM+	1
CG2303	C	IMU Blower Current	PCM+	1
CG4300	T	AGC Temp.	PCM	1
CG5000	X	PIPA FAIL	PCME	10
CG5001	X	IMU FAIL*	PCME	10
CG5002	X	CDU FAIL**	PCME	10
CG5003	X	Gimbal Lock Warning	PCME	10
CG5005	X	Error Detect	PCME	10
CG5006	X	IMU Temp. Light	PCME	10
CG5007	X	Zero Encoder Light	PCME	10
CG5008	X	IMU Delay Light	PCME	10
CG5020	X	AGC Alarm #1 (Program)	PCME	10
CG5021	X	AGC Alarm #2 (AGC Activity)	PCME	10
CG5022	X	AGC Alarm #3 (G&N FAIL)	PCME	10
CG5023	X	AGC Alarm #4 (PROG CHK FAIL)	PCME	10
CG5024	X	AGC Alarm #5 (Scalar FAIL)	PCME	10
CG5025	X	AGC Alarm #6 (Parity FAIL)	PCME	10
CG5026	X	AGC Alarm #7 (Counter FAIL)	PCME	10

*IMU Fail light/telemetry is never actuated by AGC program during Coarse Align Mode and during 5 second interval after Coarse Align.

**CDU Fail light/telemetry is never actuated by AGC program except during Fine Align Mode.

Identification		Function	Type	Sample Rate/Sec
CG5027	X	AGC Alarm #8 (Key Release)	PCME	10
CG5028	X	AGC Alarm #9 (RUPT Lock)	PCME	10
CG5029	X	AGC Alarm #10 (TC Trap)	PCME	10
CG5030	X	Computer Power Fail Light	PCME	10
CG6000	P	IMU Pressure	PCM	1
CG6020	T	PSA Temp. 1 Tray 3	PCM	1

3.5.4 Flight Qualification Tape Recorder (FQ-TR)

The G&N Flight Qualfication Tape Recorder Measurements are all classified FLIGHT QUALIFICATION*.

CG2010	V	X PIPA SG Output, in phase	TR	2000 cps
CG2030	V	Y PIPA SG Output, in phase	TR	2000 cps
CG2050	V	Z PIPA SG Output, in phase	TR	2000 cps
CG6001	D	NAV Base Roll Vibration	TR	2000 cps
CG6002	D	NAV Base Pitch Vibration	TR	2000 cps
CG6003	D	NAV Base Yaw Vibration	TR	2000 cps

The Flight Qualfication Tape Recorder has a capacity for 30 minutes of operation. This operating time is controlled by the Mission Control Programmer (MCP). The MCP logic is designed to operate the recorder over the following time intervals.

(a) Normal Mission

ON	Liftoff - 45sec	(T_o -45)
OFF	Launch Escape Tower Jettison	(T_o -172)
ON	CSM/SIVB Separation	(T_o +618)
OFF	1st SPS burn Cutoff +3 sec	(T_o +868)
ON	2nd SPS burn Ignition -4 sec	(T_o +4025)
OFF	When Recorder runs out ot tape	($\approx T_o$ +5358)

(b) Boost Abort Mission

ON	Liftoff -45 sec	(T_o -45)
OFF	Launch Escape Tower Jettison	(T_o +172)
ON	Abort Initiation (CSM/SIVB Separation)	(T_{ABORT})
OFF	When Recorder runs out of tape	($\approx T_{ABORT}$ +1583)

*See Definitions - Section 3.5.5.

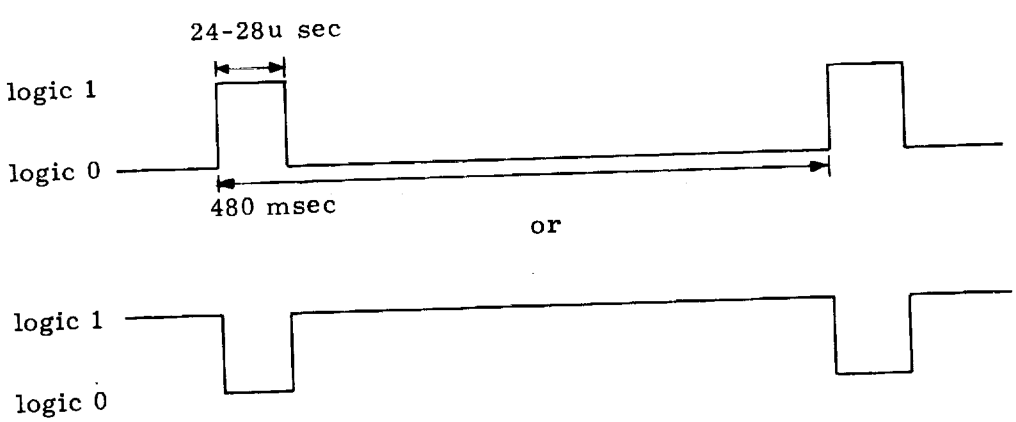
3.5.5 Definitions

OPERATIONAL	NAA defined as those measurements which will remain fixed for a block of vehicles fulfilling similar type missions. In the case of G&N however there are some differences between OPERATIONAL PCM on Mission 202 and other Block I G&N missions.
FLIGHT QUALIFICATION	NAA defined as those measurements required early in the flight program to qualify the vehicle for flight, after which they may no longer be needed.
PCM	Pulse code modulated analog measurements, digitally coded into 8 bit words for OPERATIONAL telemetry.
PCM+	Flight critical PCM measurements, which would continue to be monitored if PCM system is operated in "slow format" mode (not anticipated on Mission 202).
PCME	Special PCM measurements to monitor discrete events (i.e. on/off, open/close) using only 1 bit words.
FQ-TR	Measurements recorded on flight qualification tape recorder.

3.6 G&N Failure Detection Module

The module is composed of two sections:

(1) ELECTRONICS SECTION - Monitors the T/M ALARM signal from the AGC to the NAV DSKY. This signal is under the control of the AGC UPLINK and DOWNLINK programs and is used to control the TELEMETRY ALARM light in the NAV DSKY. Superimposed on the AGC UPLINK and DOWNLINK program's control of the signal is control by the NIGHT WATCHMAN program. This program briefly complements the existing state of the signal and then restores its initial condition.



The ELECTRONICS SECTION of the G&N Failure Detection Module monitors only the brief complement of the signal. If the complement is lacking for more than 1.6 sec* the ELECTRONICS SECTION generates the NIGHT WATCHMAN's alarm, which is a contact closure to the MCP (the G&N FAIL INDICATION), G&N ERROR LIGHT, and the S/C TELEMETRY SYSTEM, ("G&N ERROR," a TM discrete as distinguished from AGC Digital Downlink.) Should the complement pulse be restored the NIGHT WATCHMAN's alarm is removed.

(2) WIRING JUNCTION BOX

(a) Routes the NIGHT WATCHMAN's alarm to the NAA harness for the MCP, S/C TELEMETRY SYSTEM and the G&N ERROR LIGHT in the CAUTION and WARNING PANEL.

(b) Routes all remaining wires of the DSKY interface directly through the module.

The logic of the generation of the G&N FAIL INDICATION is thus under the control of the NIGHT WATCHMAN's ALARM program. This program monitors G&N activity in two phases completing a monitor cycle in 480 ms.

The first phase involves the examination of an error register (OLDERR). Should this register indicate an error present, the complement pulse would not be generated and a G&N FAIL INDICATION would result. The error register will include the following error indications:

(1) The failure of an AGC RESTART sequence. This sequence is automatically done when the AGC's normal sequences have been momentarily interrupted by failures such as TC TRAP, PARITY FAIL or a momentary loss of PRIMARY POWER. The RESTART sequence will normally perform a limited recycle of the interrupted sequence restoring the initial conditions within milliseconds.

(2) The receipt by the AGC of an indication from the Inertial Subsystem error detection circuitry of an IMU FAIL or ACCEL FAIL. Each of these fail indications is a summation of several relevant analog parameters, any one of which will cause a fail indication if exceeding the following criteria.

(a) IMU FAIL

IG Servo Error	-	greater than 4.6 mr for 2.5 ± 1 sec
MG Servo Error	-	greater than 4.6 mr for 2.5 ± 1 sec
OG Servo Error	-	greater than 4.6 mr for 2.5 ± 1 sec
3200 ~ supply	-	decrease to 50% of normal level
800 ~ supply	-	decrease to 50% of normal level

* $t < .6$ no alarm

$.6 < t < 1.6$ may alarm (dependant upon circuit tolerances)

$t > 1.6$ always alarms

The receipt of this fail indication is ignored by the AGC program when the G&N system is in the Coarse Align Mode and during the 5 second interval following Coarse Align. In this mode (used only during pre-launch alignment for Mission 202) the servo errors normally exceed the criteria above.

(b) ACCEL FAIL

X PIPA Error - greater than .32 mr for 5 ± 2 sec.

Y PIPA Error - greater than .32 mr for 5 ± 2 sec.

Z PIPA Error - greater than .32 mr for 5 ± 2 sec.

The receipt of this fail indication is ignored by the NIGHT WATCHMAN during the COAST Phase (from completion of CSM orientation to local vertical* until initiation of second +X translation).

The second phase exercises the AGC executive programs by a request for a new job (NEWJOB) via a periodic programmed interrupt (T4RUPT) with a high job priority (36 - the highest available with the exception of an alarm priority.) This new job examines bit 4 of register OUT1 and complements it as described above. Should the executive routines or the interrupt processes be disabled (as, for instance, if an AGC program had become trapped in a loop) the NEWJOB request would not be honored, the complement pulse would not be generated, and a G&N FAIL INDICATION would result.

The G&N FAIL INDICATION can also be sent to the MCP via the Up Data Link (UDL) based upon ground assessment of tracking or telemetry data. Upon receipt of G&N FAIL INDICATION the MCP immediately disables all mode commands from the AGC and commands the SCS system to SCS ΔV MODE. The attitude reference becomes the BMAGS/AGCU. The SCS system is now no longer responsive to any G&N-originated attitude signals, attitude error signals, engine on-off commands (disabled by removal of ΔV mode), or AGC commands via the MCP.

The MCP can be reset to retransfer S/C control to G&N; however, this command must come from the ground.

*Nominally 48 seconds after first burn cutoff.

4. MISSION LOGIC AND TIMELINE

4.1 Operational Constraints

The G&N system, the MCP, and the ground command systems to the G&N and the MCP must be operated within certain constraints both in normal and backup modes.

4.1.1 MCP Ground Commands

The following list details the MCP real-time commands (RTC's) planned for support of Mission 202. This list is restricted to commands to the Mission Control Programmer and is exclusive of commands to the SIVB and AGC Uplink commands:

RTC #	02...04	Fuel Cell Purge (cell#1 - cell#3)
etc.	05	Reset RTC 02-04
	10	Lifting Entry - Necessary for no-roll entry in the SCS entry mode
	11	Direct Thrust On - Turns on SPS engine; backup to onboard command in case of malfunction.
	12	Direct Thrust Off - Turns off SPS engine; backup to onboard command in case of malfunction.
	13	Reset RTC 10 - 12
	14	Direct rotation +pitch
	15	Direct rotation - pitch
	16	Direct rotation + yaw
	17	Direct rotation - yaw
	20	Direct rotation +roll
	21	Direct rotation - roll
	22	Direct Ullage
	23	Reset RTC 14 - 22
	24/32	SM Quad A Propellant Off/On
	25/33	SM Quad B Propellant Off/On
	26/34	SM Quad C Propellant Off/On
	27/35	SM Quad D Propellant Off/On
	30/36	CM System A Propellant Off/On
	31/37	CM System B Propellant Off/On
	40	Let Jettison Start-Backup to onboard command from SIVB
	41	G&N Failure - Backup to G&N function
	42	G&N Failure Inhibit - Reset G&N failure
	43	Reset RTC 41-42
	44	Roll Rate Gyro Backup - Switches roll BMAG to rate mode and uses this gyro for roll rate data

RTC # etc.	45	Pitch Rate Gyro Backup - Switches pitch BMAG to rate mode and uses this gyro for pitch rate data
	46	Yaw Rate Gyro Backup - Switches yaw BMAG to rate mode and uses this gyro for yaw data
	47	FDAI align
	50	Reset RTC 44 - 47
	51	-Z Antenna ON
	52	+Z Antenna ON
	53	G&N Antenna Switching - Enable of G&N command capability for Antenna Switching
	54	Roll A and C Channel Disable - Disables the automatic A and C RCS channels
	55	Roll B and D Channel Disable - Disables the automatic B and D RCS roll channels
	56	Pitch Channel Disable - Disables the automatic pitch RCS channels
	57	Yaw Channel Disable - Disables the automatic yaw RCS channels
	60	Reset RTC 54 - 57
	61	CM/SM Separation - Backup to onboard command from the G&N
	62-67	See below
	70	Reset RTC 64-67
	71	Abort (Also Backup for SIVB/CSM Separation Start)
	72	Reset RTC 73 - 77

Commands 14-17, 20-21, and 54-57 will be used to control S/C attitude in cases where the G&N is not operable. Commands 62-67 are not operable on Mission 202. They are commands for 500 series mission use only.

Of these commands only six are intimately concerned with G&N operation: RTC 11, 12, 22, 41, 42 and 71.

RTC 11- Direct Thrust On:	AGC Engine On logic presently includes a monitor of ΔV to ensure engine ignition. This monitor continues for 10 sec after sensing no thrust during which time the ground might start the SPS engine. If suitable ΔV has not been sensed after 10 seconds the AGC would exit from thrust vector control and hold attitude until the free-fall interrupt occurs. Should the ground successfully start the engine within 10 sec the AGC will guide the burn normally. It must be assumed however that as the AGC

Engine On Command did not work correctly, AGC Engine Off will not either. The ground must therefore command a timely "Thrust Off" compatible with the AGC TVC calculation.

RTC 12-Direct Thrust Off: The ground may thus inhibit starting of or may stop the SPS thrust. Should AGC-controlled firing be inhibited or shutdown the ΔV monitor logic would after 10 seconds exit from thrust vector control and hold attitude until the free-fall interrupt occurs.

RTC 22-Direct Ullage: A backup command for ground use during a ground controlled burn in the SCS ΔV mode. Its use during G&N controlled flight would inhibit G&N attitude control with the possibility of the G&N being unaware of the loss.

RTC 41-G&N Failure: This command is a ground backup for the G&N originated command. All control of the vehicle by G&N is thereby inhibited.

RTC 42-G&N Failure Inhibit: This command overrides the G&N FAIL signal. Use of this command does not guarantee that the AGC will correctly resume control of the S/C.

RTC 71-Abort: This command initiates SIVB/CSM Separation in a boost abort. For appropriate AGC action, it must be accompanied by an abort command to the AGC via AGC Uplink.

The G&N BACKUP ABORT command, previously a backup to RTC 71, has been deleted from the AGC/MCP interface (see para. 3.2.2 section 10).

4.1.2 Backup Attitude Reference System

The backup attitude reference system is the SCS BMAGs in conjunction with AGCU. G&N control of the CSM orientation is always done with consideration for the maintenance and accuracy of this system. As the SCS system is presently designed, the BMAGs operate as free gyros in the G&N ΔV MODE; in other modes they are caged through the AGCU.

As the mechanical stops of the BMAG's are at $\pm 17^{\circ}$ it is apparent that during boost (MONITOR MODE) and attitude maneuvers (G&N ATTITUDE CONTROL OR ENTRY MODES) both involving angular changes of over 17° the BMAG's must be caged. In the G&N ΔV mode however, should attitude changes over 17° occur, integrity of the backup attitude system will be lost. Such changes are not anticipated in the nominal mission.

The rate limits of the backup attitude reference system in the caged mode are 5°/sec in Pitch and Yaw and 20°/sec in Roll. To preclude controlling the S/C rates beyond which the backup attitude reference system can maintain its reference, the G&N will limit its command rate to the CSM and CM.

4.1.3 Backup Entry Control

During the pre-entry coast the G&N system must orient the CM for aerodynamic trim and lift vector down. Then, in the event of G&N FAIL INDICATION, the MCP/SCS will hold this attitude until it senses a prescribed "g" level at which time it will command a continuous roll angular velocity.

4.1.4 External Data Requirements

G&N requirements for external data fall into three categories:

a) Navigation Data via the Uplink
No requirement for this data is made at this time.

b) Radar Tracking Data for Post Flight Analysis

Tracking data requirements, to a degree of accuracy and completeness which would permit the most comprehensive determination of G&N flight performance, are given in Table 4-1. Subsequent revisions of this plan will reflect more realistic requirements.

c) Radar Tracking Data for Real-Time Monitor of G&N

This requirement is given by Table 4-2, which is derived from the total indication error expected in the position and velocity data telemetered to the ground via the AGC DOWNLINK.

TABLE 4-1

EXTERNAL TRACKING DATA REQUIREMENTS
TO SUPPORT POST FLIGHT ANALYSIS OF G&N

Three orthogonal components of position and velocity are required in IMU coordinates at one-second intervals during each powered phase. The required accuracies are given in this table in local vertical coordinates.

Phase	one sigma Position Error (ft)			one sigma Velocity Error (fps)		
	Alt.	Track	Range	Alt.	Track	Range
S-IB Boost	200	1900	100	0.9	7.2	0.4
1st SPS Burn	40	210	30	0.3	1.8	0.2
2nd, 3rd, 4th SPS Burns	10	30	10	0.3	0.6	0.2
Entry	1100	1000	200	4.6	4.9	0.8

TABLE 4-2

EXTERNAL TRACKING DATA REQUIREMENTS
TO PROVIDE REAL-TIME MONITOR OF G&N

Three orthogonal components of position and velocity are required in IMU coordinates at one-second intervals during each powered phase. The required accuracies are given in this table in local vertical coordinates.

Phase	one sigma Position Error (ft)			one sigma Velocity Error (fps)		
	Alt.	Track	Range	Alt.	Track	Range
S-IB Boost	200	1900	100	0.9	7.2	0.4
1st SPS Burn	400	3900	300	1.4	8.0	0.8
2nd, 3rd, 4th SPS Burns	2300	4000	7200	7.3	7.4	1.8
Entry	2900	7300	8800	11.6	3.9	2.9

4.2 AGC Program Logic, Mission 202 (202 * REL 2)

The following diagrams illustrate the presently programmed AGC logic for Mission 202.

A program timeline shows the major program sections operating during each phase of the mission along with a functional description of each.

The block diagrams following the timeline expand in detail on each of these program sections and serve to explain fully the AGC logic involved in guidance, (navigation), and spacecraft control functions. Certain details are added to assist the reader in following through the actual program print out.

Dotted lines on the Logic Diagrams represent waitlist calls. The time interval represented equals the time notated to the right of the dotted line minus elapsed AGC computation time from initiation of the call (usually $\ll$ 1 Sec).

The terminology used is defined as follows:

Establish - Cause a specified job to be performed under executive control.

ENDOFJOB - Terminate a job.

Call - Cause a specified task to be started at a specified time, under AGC waitlist control. A task may interrupt a job and, once called, continues to completion.

TASKOVER - Terminate a task.

Do - Branch to a routine with a return to the next operation in sequence.

Set - Cause an "on" state of a specified bit in a register.

Remove - Cause an "off" state of a specified bit in a register.

Store - Store indicated quantity in erasable for future reference.

T - Present time.

TFF - Free fall time to 400, 000 ft altitude (or 280,000 ft for aborts).

The "on" state of flagwords used are defined as follows:

FLAGWRD1		Bit #
TUMBFLAG	Tumble state detected	1
LIFTFLAG	Liftoff has occurred	2
ENTRYFLAG	Ready for entry	3
STEERFLAG	TVC steering mode on	4
DVMONFLAG	ΔV monitor on	5
MONITFLAG	Saturn attitude monitor on	6
INT1FLAG	TFF $<$ 160 Sec	7

FLAGWRD1		BIT #
S4BSMFLAG	S4BSM separation has occurred	8
INITFLAG	Initial VR, thrust attitude computation	9
INTPFLAG	Free fall interrupt enabled	10
ACTIVFLG	Inertial compensation control flag	11
SHTDNFLAG	Prepare for separation & entry	12
VERTFLAG	Local vertical control on	13
UPDATFLAG	Received R, V, T update	14
COASTFLAG	In coast phase	15

FLAGWRD2

ARRSTFLG	Tumble arrest burn	Burn Switches	1
ABRTFLAG	Abort burn		2
TABTFLAG	Burn after tumble arrest		3
SPS1FLAG	SPS1 burn		4
SPS2FLAG	SPS2 burn		5
SPS3FLAG	SPS3 burn		6
SPS4FLAG	SPS4 burn		7
BEGINFLG	Control flags for S/C attitude maneuvers via ATTIJOB, DOMANU, & CALCMANU		8
NEGFLAG			9
DOMANFLAG			10
CALCFLAG			11
ROLLFLAG			12
BACKFLAG			13
CDUXFLAG	Enabled prior to CM/SM separation		14
DRIFTFLAG	Enables free fall gyro compensation		15

MISSION 202 PROGRAM TIMELINE

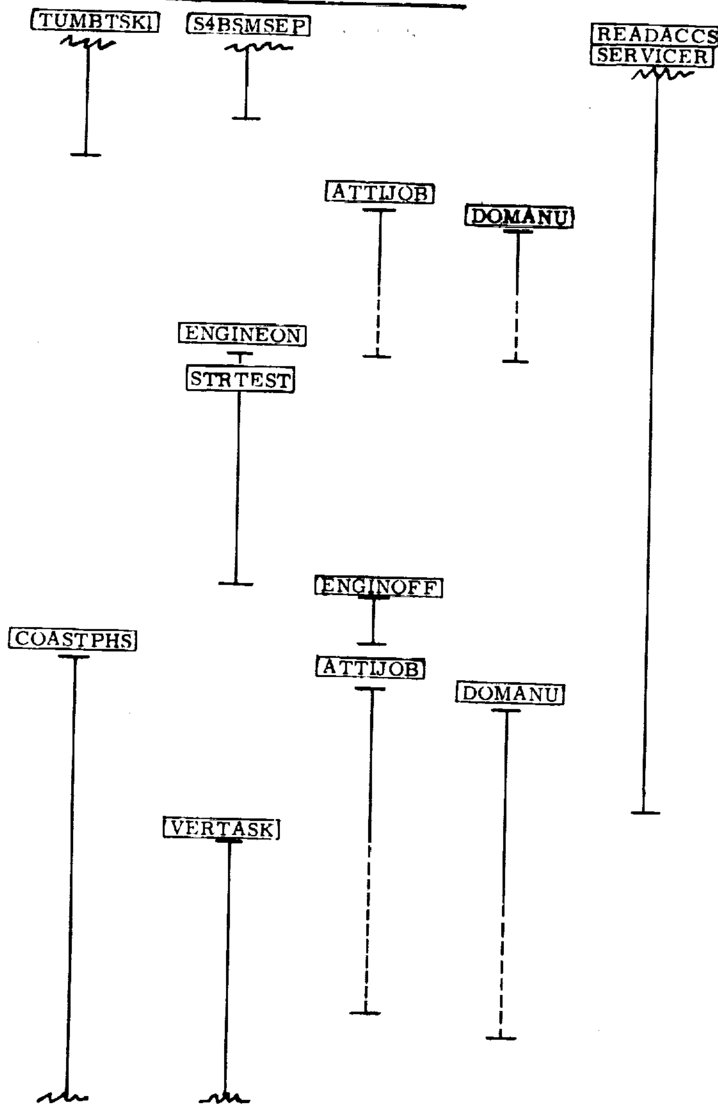
Time	Major Event	Operating Program Section	Functional Description
To -11 hrs	Initiate Prelaunch	PRELAUNCH	Prelaunch Alignment (Gyro-Compassing and Vertical Erection):
To -1 hr	S/C Closeout		Final G&N systems check:
To -5 sec	Guidance Ref. Release	READACCS SERVICER	Saturn Guidance and IMU go Inertial. READACCS and SERVICER initiated. (Cycle independently during burns). READACCS reads PIPA's and establishes SERVICER which updates RN and VN via CALCRVG and computes TFF via CALCTFF.
To	Liftoff	LIFTOFF	LIFTOFF monitors vehicle attitude via MON2JOB which drives CDU's to precomputed boost angles. Ground monitors CDU errors.
To +136	Terminate Attitude Monitor		LIFTOFF terminated at this precomputed time.
To +151	SIVB Ignition		
To +169	Initiate Tumble Monitor	TUMBTSK1	TUMBTSK1 initiated at this precomputed time. (Monitors vehicle attitude rates via TUMBJOB).
To +172	Let Jettison		
To +619	SIVB/CSM SEP	S4BSMSEP	S4BSMSEP determines if tumble, abort, or SPS1 burn.

Footnotes:

1. Normal Sequence of events is shown in timeline.
2. Terms in Blocks ☐ refer to program section titles that have a separate page of description. Each page may describe more actions than is described by the mnemonic.
3. Terms underlined identify a location within the program.

Time	Major Event
To +619	SIVB/CSM SEP
To +631	SPSI Engine On
To +865	SPSI Engine Off
To +913	Initiate Vertical Phase

Operating Program Section



Functional Description

SERVICER checks TFF; computes desired initial SPSI burn attitude via BURNINIT and obtains attitude via ATTIJOB which controls CALCMANU in computing, timing, and performing, via DOMANU maneuver sequences.

ENGINEON sets engine on and establishes ROLLJOB which maintains wings level attitude during burns.

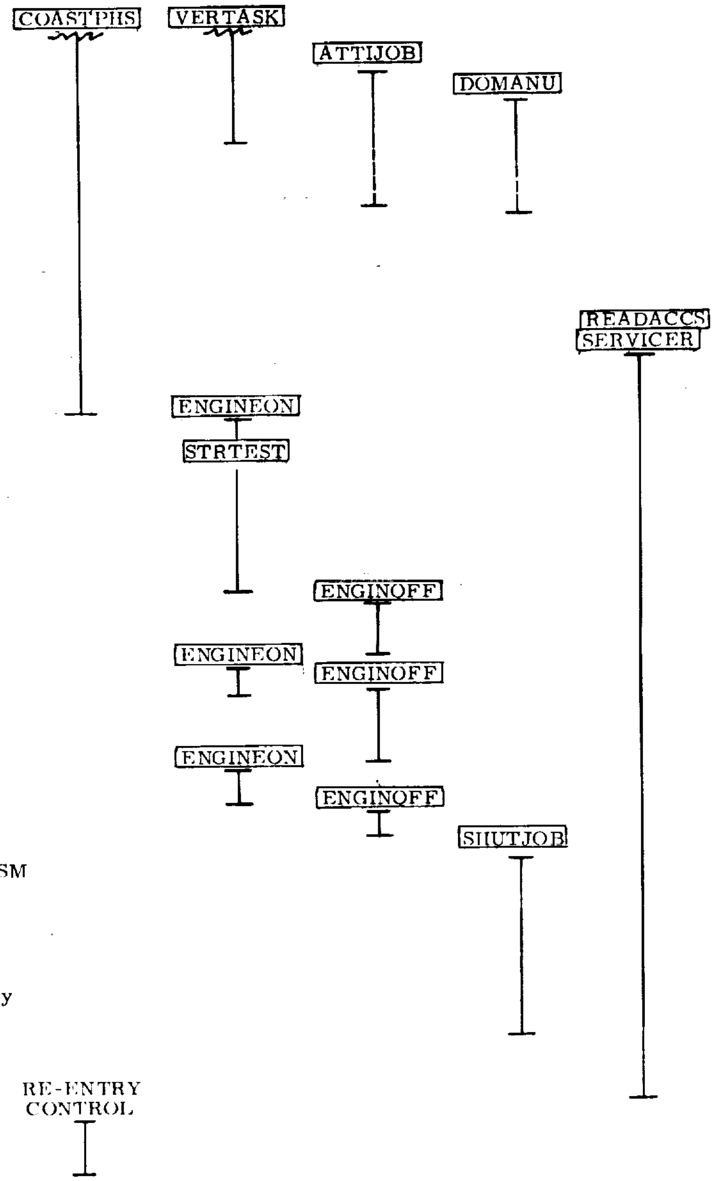
SERVICER starts STRTEST which performs cross-product steering and eventually calls ENGINOFF

ENGINOFF sets engine off.

COASTPHS computes vertical coast attitude via VERTINIT; and obtains attitude via ATTIJOB, CALCMANU, and DOMANU as before. READACCS and SERVICER inactive during coast. VERTASK establishes VERTIJOB to compute local radius vector via CALCRVG and to compute steering signals for maintaining local vertical attitude.

Time	Major Event
To +2902	Vertical phase over. Initiate maneuver to SPS2 attitude
To +3999	+X Trans. On
To +4029	SPS2 Engine On
To +4113	SPS2 Engine Off
To +4123	SPS3 Engine On
To +4126	SPS3 Engine Off
To +4136	SPS4 Engine On
To +4139	SPS4 Engine Off
To +4247	160 TFF
To +4248	Maneuver to CM/SM Sep. Attitude
To +4313	95 TFF
To +4323	CM/SM Separation
To +4328	Maneuver to Entry Attitude
To +4482	0.05g sensed
To +5229	40000 ft (Splash)

Operating Program Section



Functional Description

At completion of vertical phase AVETOMDI computes SPS2 initial burn point. VERTASK computes desired SPS2 initial attitude via CALCRAV, 202SPS2, and BURNINIT; and obtains attitude via ATTIJOB, CALCMANU and DOMANU as before.

COASTPHS reactivates READACCS and SERVICER; and calls ENGINEON.

ENGINEON sets engine on.

SERVICER starts STRTEST which performs cross-product steering and calls ENGINOFF.

ENGINOFF sets Engine Off.

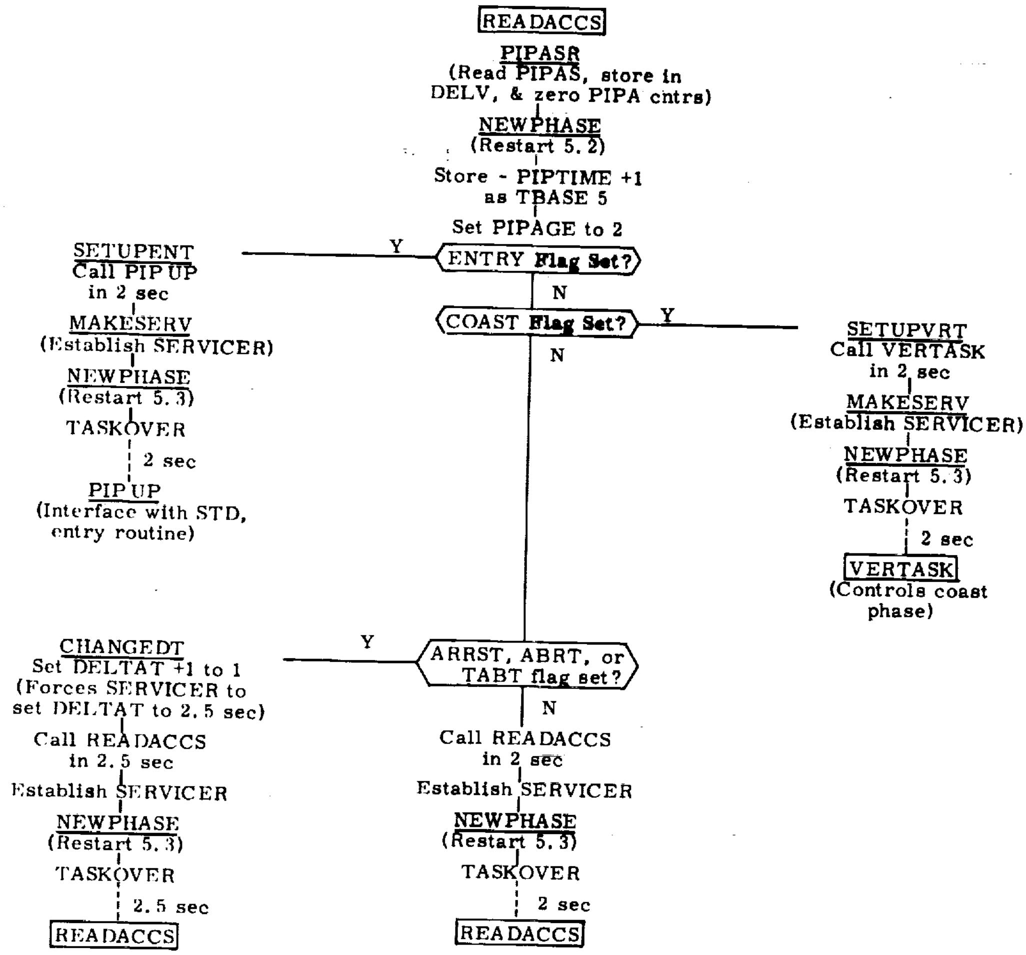
The 3 sec SPS 3 and SPS4 burns proceed at 10 sec intervals, at SPS2 cut-off attitude.

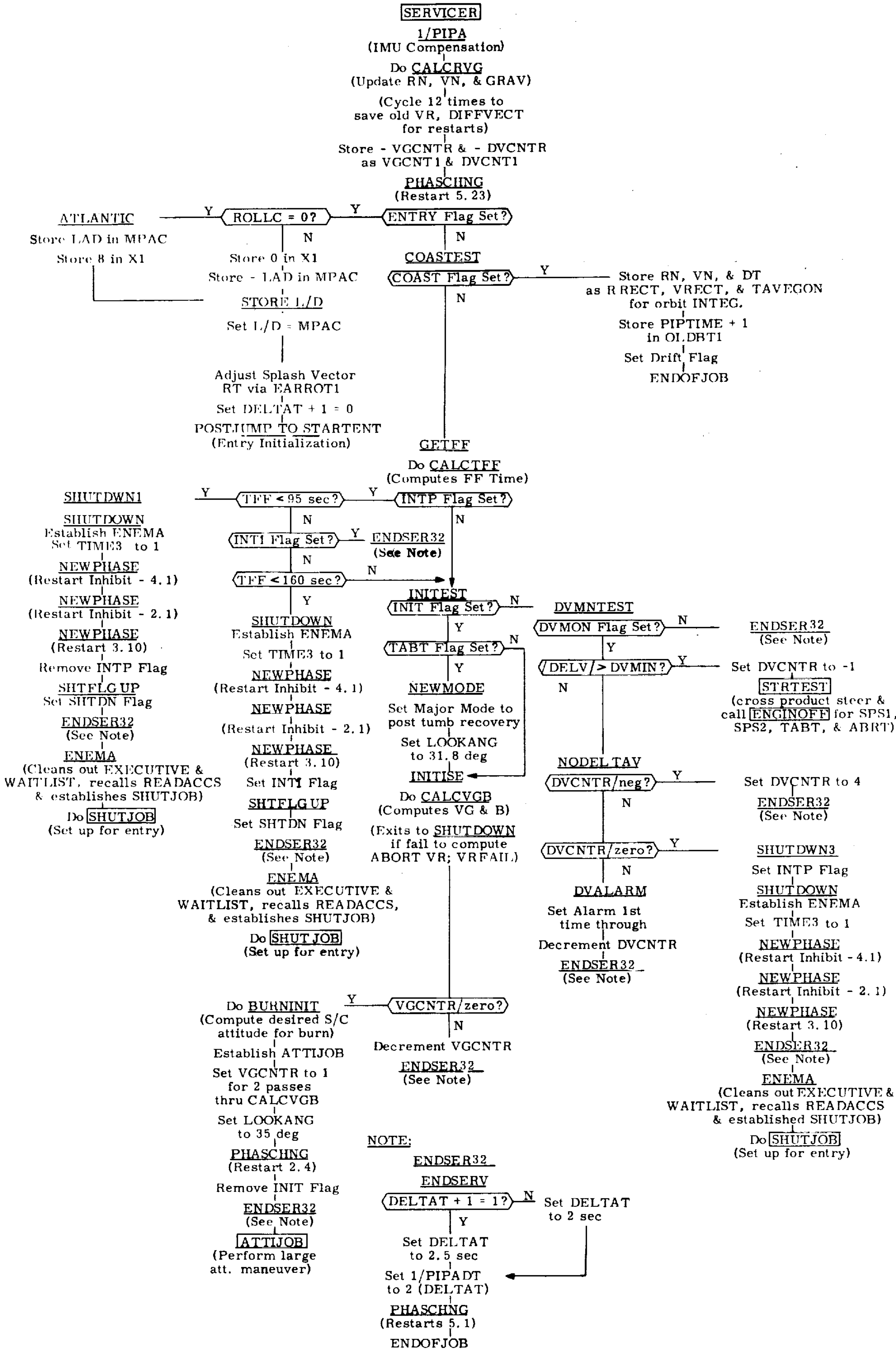
SERVICER, via F.F. interrupts, initiates pre-entry routines via SHUTJOB. SEPMANU computes and performs attitude maneuver for CM/SM separation.

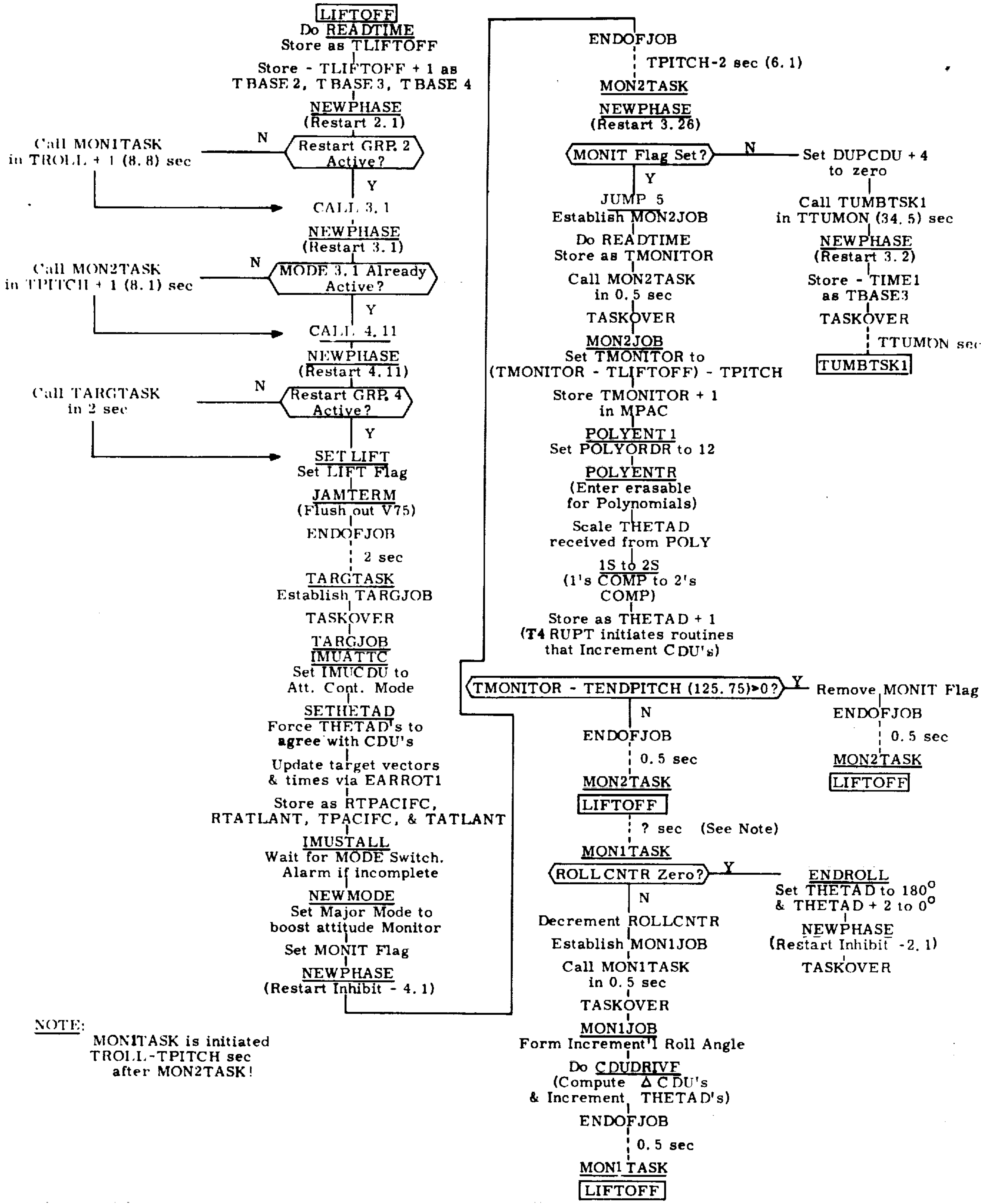
ENTAJOB computes and performs attitude maneuver for entry.

SERVICER updates target vector for entry routines.

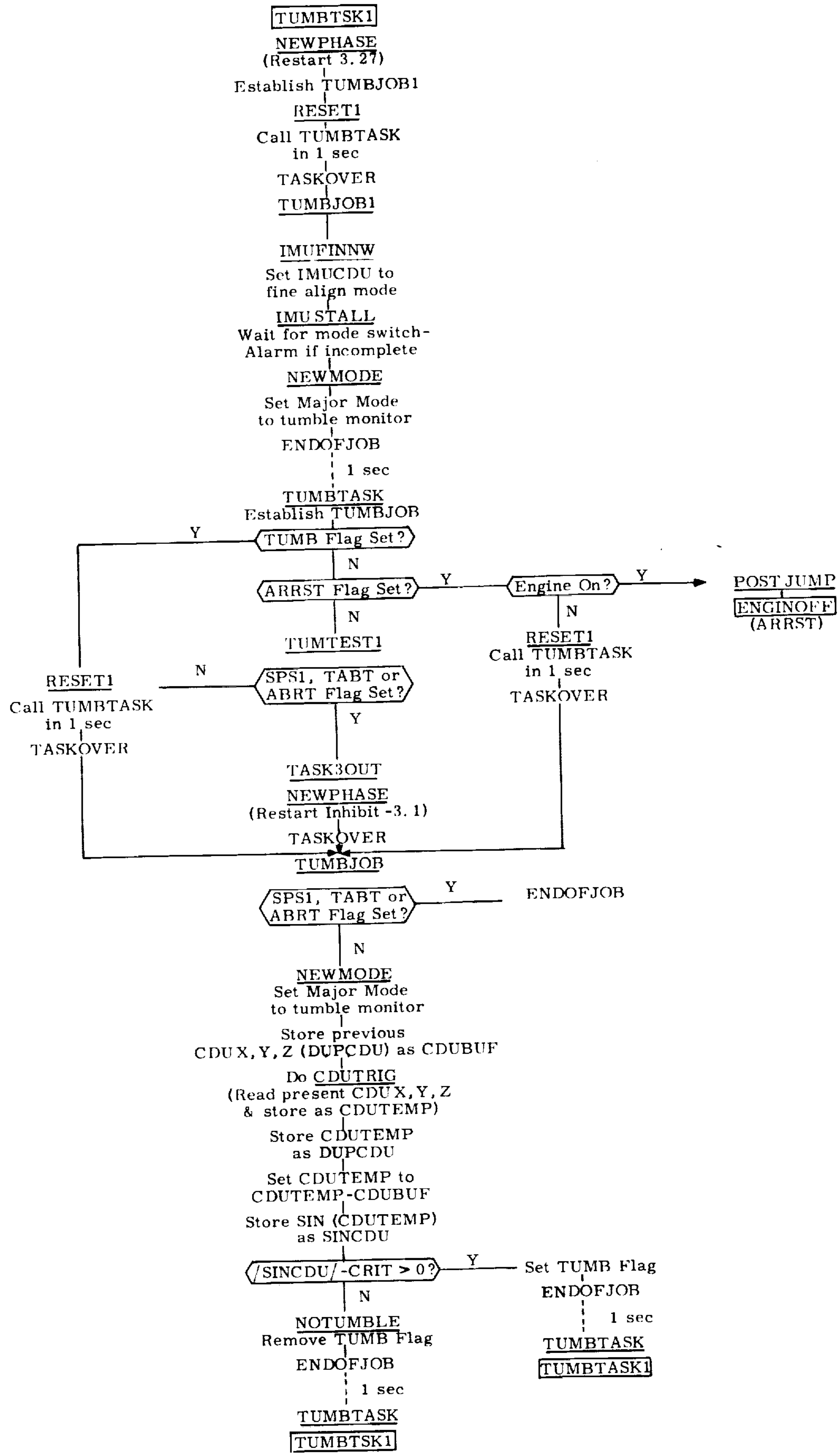
RE-ENTRY CONTROL controls vehicle during atmospheric entry phase.

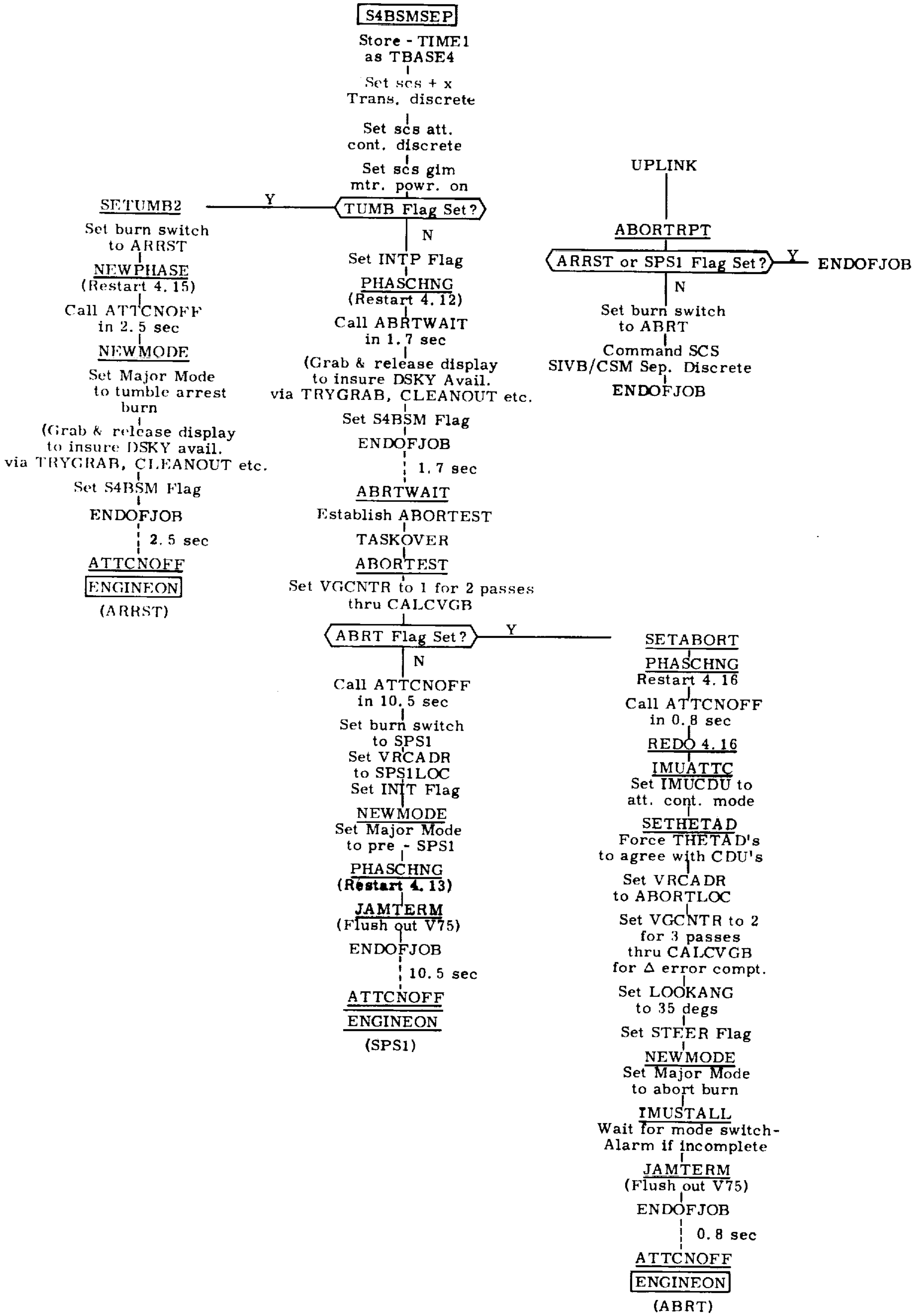

READACCS
PIPASR
(Read PIPAS, store in DELV, & zero PIPA cntrs)
NEWPHASE
(Restart 5.2)
Store - PIPTIME +1 as TBASE 5
Set PIPAGE to 2
ENTRY Flag Set?
Y
N
SETUPENT
Call PIPUP in 2 sec
MAKESERV
(Establish SERVICER)
NEWPHASE
(Restart 5.3)
TASKOVER
2 sec
PIPUP
(Interface with STD, entry routine)
COAST Flag Set?
Y
N
SETUPVRT
Call VERTASK in 2 sec
MAKESERV
(Establish SERVICER)
NEWPHASE
(Restart 5.3)
TASKOVER
2 sec
VERTASK
(Controls coast phase)
ARRST, ABRT, or TABT flag set?
Y
N
CHANGEDT
Set DELTAT +1 to 1
(Forces SERVICER to set DELTAT to 2.5 sec)
Call READACCS in 2.5 sec
Establish SERVICER
NEWPHASE
(Restart 5.3)
TASKOVER
2.5 sec
READACCS
Call READACCS in 2 sec
Establish SERVICER
NEWPHASE
(Restart 5.3)
TASKOVER
2 sec
READACCS

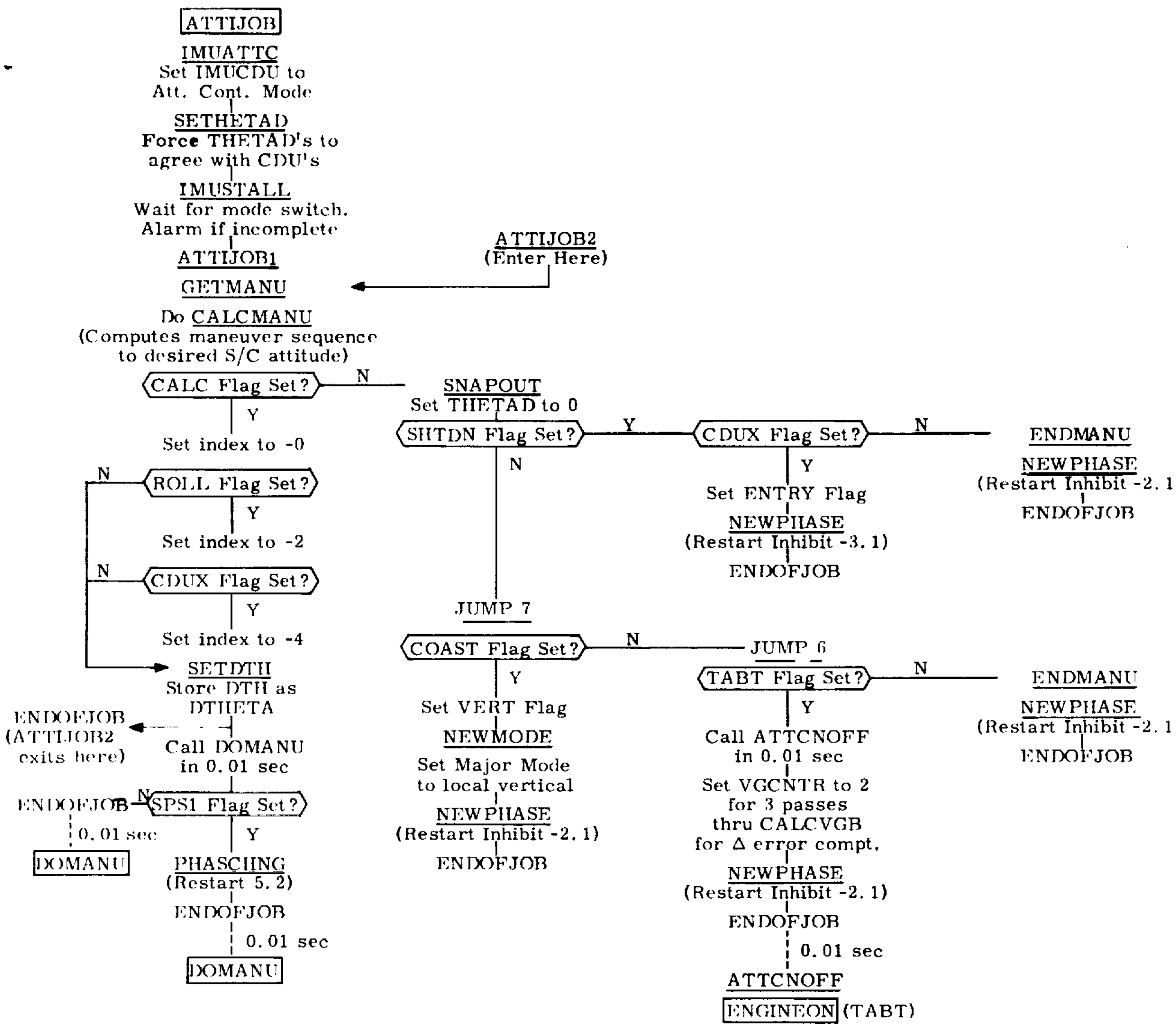

SERVICER
1/PIPA
(IMU Compensation)
Do CALCRVG
(Update RN, VN, & GRAV)
(Cycle 12 times to save old VR, DIFFVECT for restarts)
Store - VGCNTR & - DVCNTR as VGCNT1 & DVCNT1
PHASCHNG
(Restart 5.23)
ENTRY Flag Set?
Y
N
ROLLC = 0?
Y
N
ATLANTIC
Store LAD in MPAC
Store 8 in X1
Store 0 in X1
Store - LAD in MPAC
STORE L/D
Set L/D = MPAC
Adjust Splash Vector RT via EARROT1
Set DELTAT + 1 = 0
POSTJUMP TO STARTENT
(Entry Initialization)
COASTEST
COAST Flag Set?
Y
N
Store RN, VN, & DT as RRECT, VRECT, & TAVEGON for orbit INTEG.
Store PIPTIME + 1 in OLDBT1
Set Drift Flag
ENDOFJOB
GETFF
Do CALCTFF
(Computes FF Time)
INTP Flag Set?
Y
N
TFF < 95 sec?
Y
N
SHUTDWN1
SHUTDOWN
Establish ENEMA
Set TIME3 to 1
NEWPHASE
(Restart Inhibit - 4.1)
NEWPHASE
(Restart Inhibit - 2.1)
NEWPHASE
(Restart 3.10)
Remove INTP Flag
SHTFLG UP
Set SHTDN Flag
ENDSER32
(See Note)
ENEMA
(Cleans out EXECUTIVE & WAITLIST, recalls READACCS & establishes SHUTJOB)
Do SHUTJOB
(Set up for entry)
INT1 Flag Set?
Y
N
ENDSER32
(See Note)
TFF < 160 sec?
Y
N
SHUTDOWN
Establish ENEMA
Set TIME3 to 1
NEWPHASE
(Restart Inhibit - 4.1)
NEWPHASE
(Restart Inhibit - 2.1)
NEWPHASE
(Restart 3.10)
Set INT1 Flag
SHTFLG UP
Set SHTDN Flag
ENDSER32
(See Note)
ENEMA
(Cleans out EXECUTIVE & WAITLIST, recalls READACCS, & establishes SHUTJOB)
Do SHUT JOB
(Set up for entry)
INITEST
INIT Flag Set?
Y
N
TABT Flag Set?
Y
N
NEWMODE
Set Major Mode to post tumb recovery
Set LOOKANG to 31.8 deg
INITISE
Do CALCVGB
(Computes VG & B)
(Exits to SHUTDOWN if fail to compute ABORT VR; VRFAIL)
VGCNTR/zero?
Y
N
Do BURNINIT
(Compute desired S/C attitude for burn)
Establish ATTIJOB
Set VGCNTR to 1 for 2 passes thru CALCVGB
Set LOOKANG to 35 deg
PHASCHNG
(Restart 2.4)
Remove INIT Flag
ENDSER32
(See Note)
ATTIJOB
(Perform large att. maneuver)
Decrement VGCNTR
ENDSER32
(See Note)
DVMNTEST
DVMON Flag Set?
Y
N
ENDSER32
(See Note)
|DELV| > DVMIN?
Y
N
Set DVCNTR to -1
STRTEST
(cross product steer & call ENGINOFF for SPS1, SPS2, TABT, & ABRT)
NODELTAV
DVCNTR/neg?
Y
N
Set DVCNTR to 4
ENDSER32
(See Note)
DVCNTR/zero?
Y
N
DVALARM
Set Alarm 1st time through
Decrement DVCNTR
ENDSER32
(See Note)
SHUTDWN3
Set INTP Flag
SHUTDOWN
Establish ENEMA
Set TIME3 to 1
NEWPHASE
(Restart Inhibit - 4.1)
NEWPHASE
(Restart Inhibit - 2.1)
NEWPHASE
(Restart 3.10)
ENDSER32
(See Note)
ENEMA
(Cleans out EXECUTIVE & WAITLIST, recalls READACCS & established SHUTJOB)
Do SHUTJOB
(Set up for entry)
NOTE:
ENDSER32
ENDSERV
DELTAT + 1 = 1?
N
Y
Set DELTAT to 2 sec
Set DELTAT to 2.5 sec
Set 1/PIPADT to 2 (DELTAT)
PHASCHNG
(Restarts 5.1)
ENDOFJOB

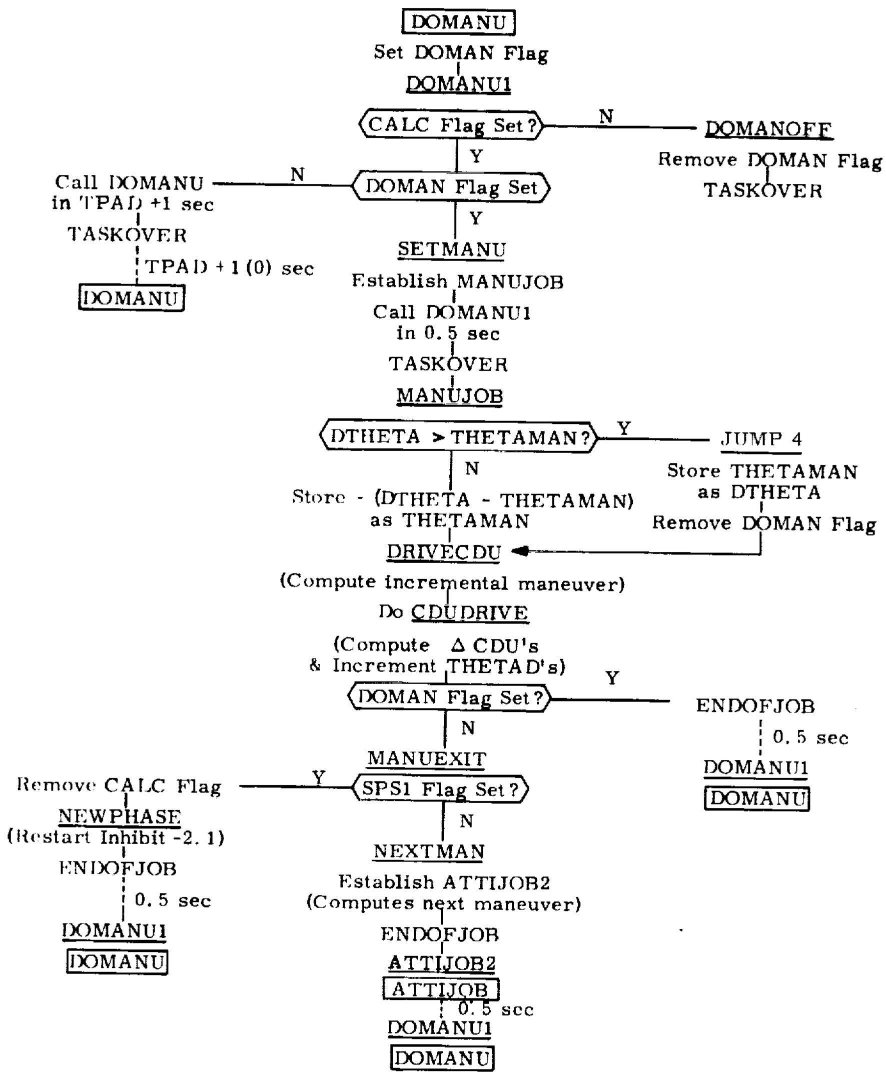


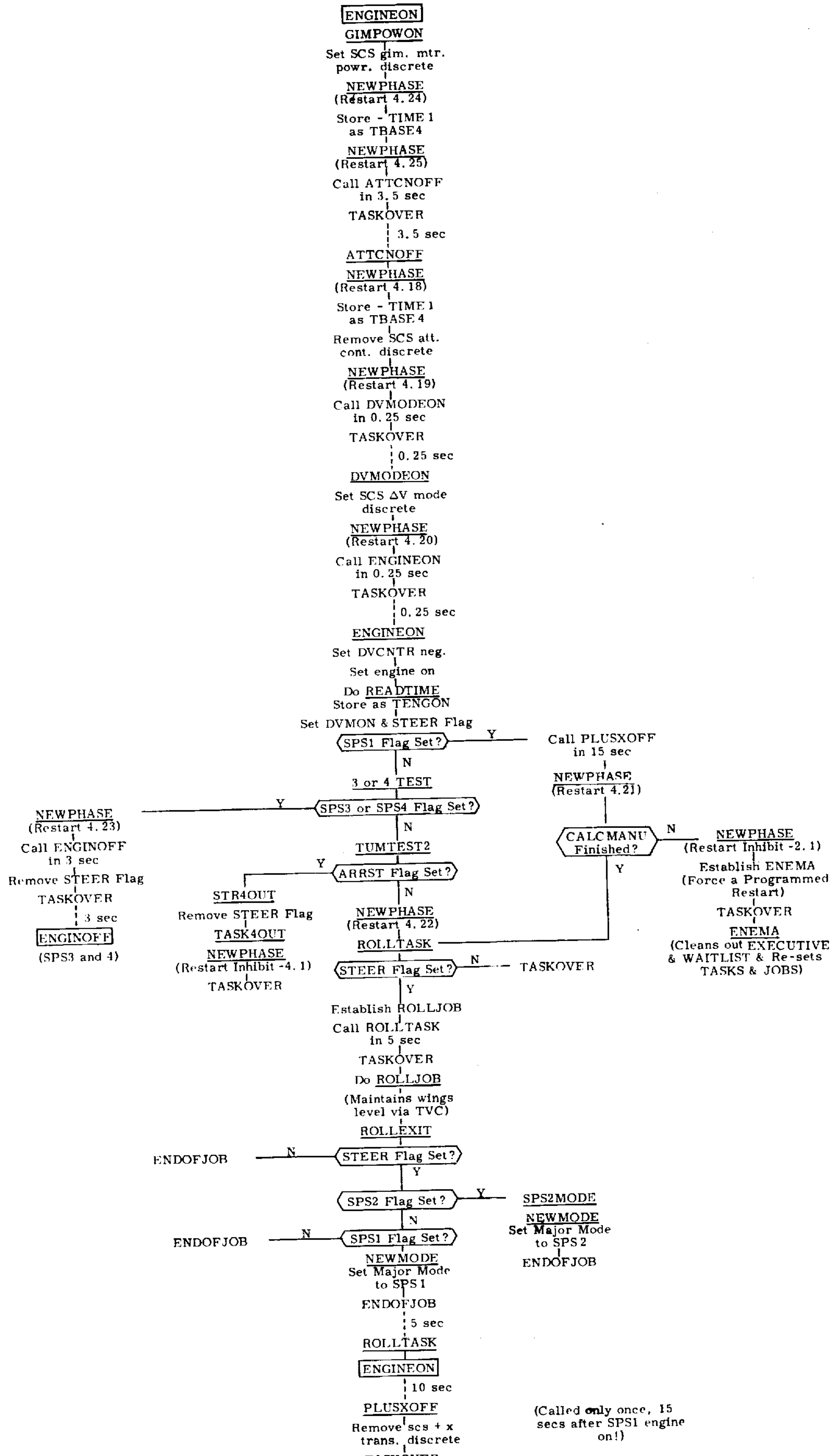
NOTE:
MON1TASK is initiated
TROLL-TPITCH sec
after MON2TASK!


TUMBTSK1
NEWPHASE
(Restart 3.27)
Establish TUMBJOB1
RESET1
Call TUMBTASK
in 1 sec
TASKOVER
TUMBJOB1
IMUFINNW
Set IMUCDU to
fine align mode
IMU STALL
Wait for mode switch-
Alarm if incomplete
NEWMODE
Set Major Mode
to tumble monitor
ENDOFJOB
1 sec
TUMBTASK
Establish TUMBJOB
TUMB Flag Set?
Y
N
ARRST Flag Set?
Y
Engine On?
Y
POST JUMP
ENGINOFF
(ARRST)
N
RESET1
Call TUMBTASK
in 1 sec
TASKOVER
N
TUMTEST1
N
RESET1
Call TUMBTASK
in 1 sec
TASKOVER
SPS1, TABT or
ABRT Flag Set?
Y
TASK3OUT
NEWPHASE
(Restart Inhibit -3.1)
TASKOVER
TUMBJOB
SPS1, TABT or
ABRT Flag Set?
Y
ENDOFJOB
N
NEWMODE
Set Major Mode
to tumble monitor
Store previous
CDUX, Y, Z (DUPCDU) as CDUBUF
Do CDUTRIG
(Read present CDUX, Y, Z
& store as CDUTEMP)
Store CDUTEMP
as DUPCDU
Set CDUTEMP to
CDUTEMP-CDUBUF
Store SIN (CDUTEMP)
as SINCDU
/SINCDU/ -CRIT > 0?
Y
Set TUMB Flag
ENDOFJOB
1 sec
TUMBTASK
TUMBTASK1
N
NOTUMBLE
Remove TUMB Flag
ENDOFJOB
1 sec
TUMBTASK
TUMBTSK1

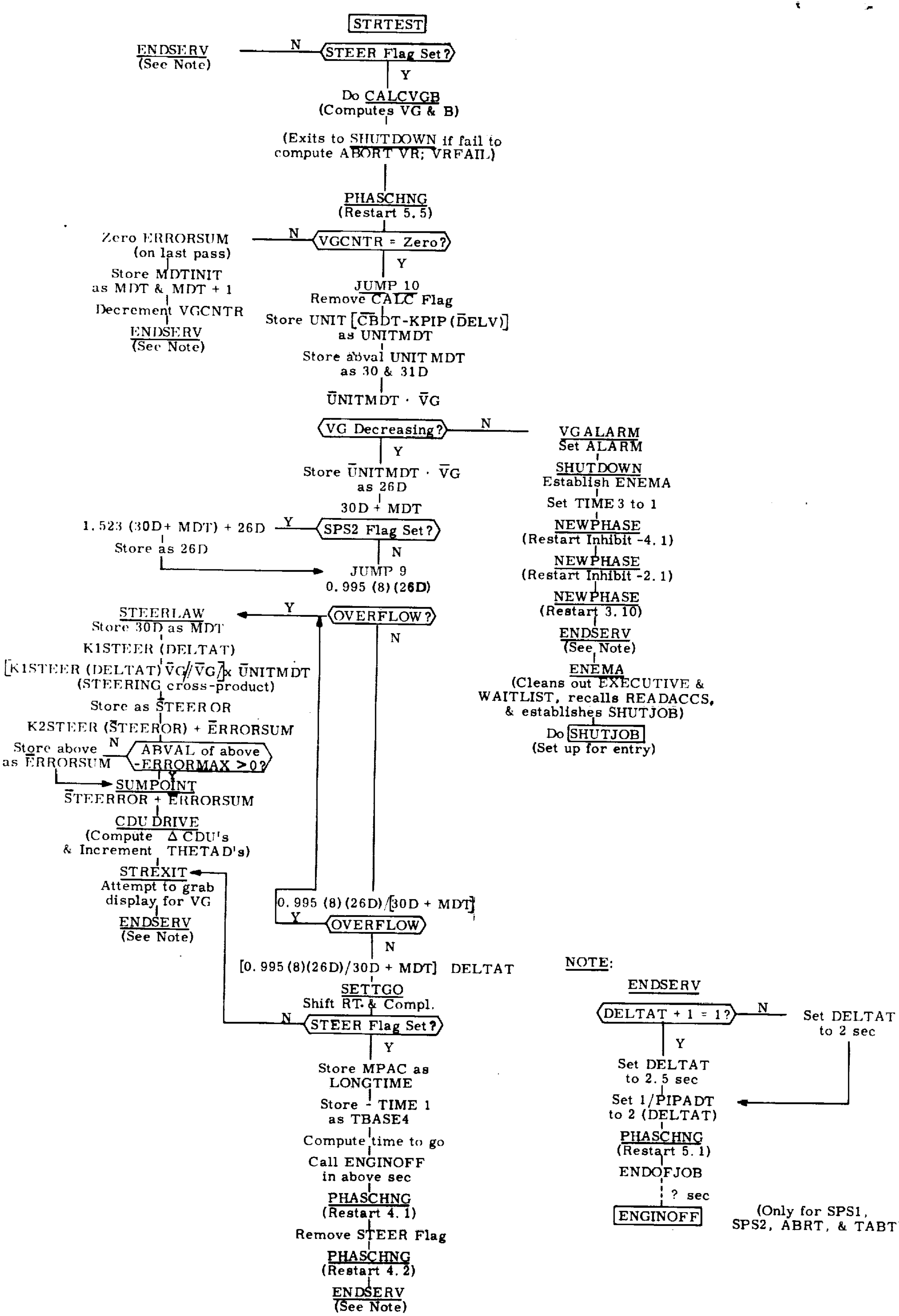

S4BSMSEP
Store - TIME1 as TBASE4
Set scs + x Trans. discrete
Set scs att. cont. discrete
Set scs gim mtr. powr. on
TUMB Flag Set?
Y
N
SETUMB2
Set burn switch to ARRST
NEWPHASE
(Restart 4.15)
Call ATTCNOFF in 2.5 sec
NEWMODE
Set Major Mode to tumble arrest burn
(Grab & release display to insure DSKY avail. via TRYGRAB, CLEANOUT etc.
Set S4BSM Flag
ENDOFJOB
2.5 sec
ATTCNOFF
ENGINEON
(ARRST)
Set INTP Flag
PHASCHNG
(Restart 4.12)
Call ABRTWAIT in 1.7 sec
(Grab & release display to insure DSKY Avail. via TRYGRAB, CLEANOUT etc.
Set S4BSM Flag
ENDOFJOB
1.7 sec
ABRTWAIT
Establish ABORTEST
TASKOVER
ABORTEST
Set VGCNTR to 1 for 2 passes thru CALCVGB
ABRT Flag Set?
Y
N
Call ATTCNOFF in 10.5 sec
Set burn switch to SPS1
Set VRCADR to SPS1LOC
Set INIT Flag
NEWMODE
Set Major Mode to pre - SPS1
PHASCHNG
(Restart 4.13)
JAMTERM
(Flush out V75)
ENDOFJOB
10.5 sec
ATTCNOFF
ENGINEON
(SPS1)
UPLINK
ABORTRPT
ARRST or SPS1 Flag Set?
Y
ENDOFJOB
N
Set burn switch to ABRT
Command SCS SIVB/CSM Sep. Discrete
ENDOFJOB
SETABORT
PHASCHNG
Restart 4.16
Call ATTCNOFF in 0.8 sec
REDO 4.16
IMUATTC
Set IMUCDU to att. cont. mode
SETHETAD
Force THETAD's to agree with CDU's
Set VRCADR to ABORTLOC
Set VGCNTR to 2 for 3 passes thru CALCVGB for Δ error compt.
Set LOOKANG to 35 degs
Set STEER Flag
NEWMODE
Set Major Mode to abort burn
IMUSTALL
Wait for mode switch- Alarm if incomplete
JAMTERM
(Flush out V75)
ENDOFJOB
0.8 sec
ATTCNOFF
ENGINEON
(ABRT)

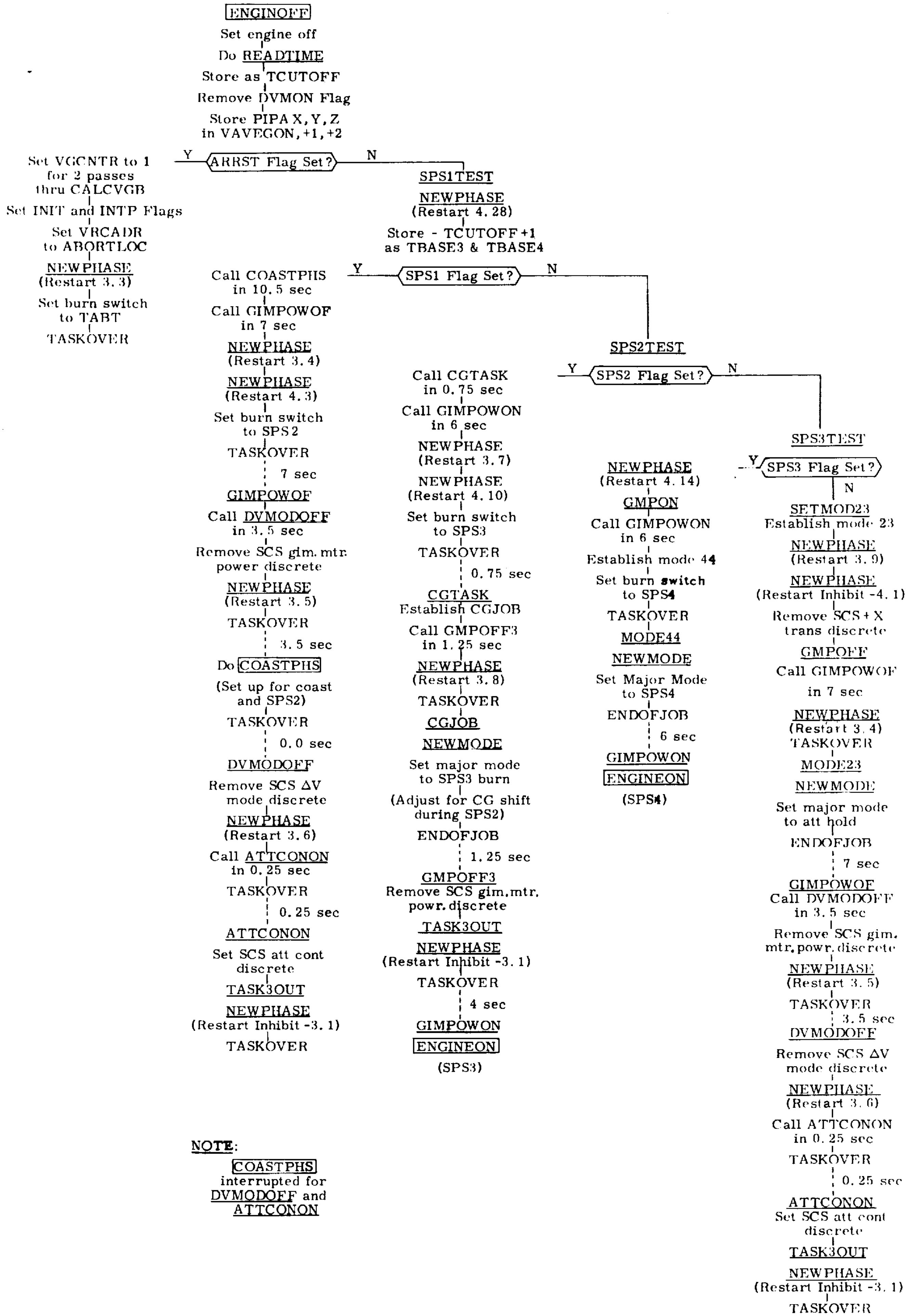

ATTIJOB
IMUATTC
Set IMUCDU to Att. Cont. Mode
SETHETAD
Force THETAD's to agree with CDU's
IMUSTALL
Wait for mode switch. Alarm if incomplete
ATTIJOB1
ATTIJOB2
(Enter Here)
GETMANU
Do CALCMANU
(Computes maneuver sequence to desired S/C attitude)
CALC Flag Set?
N
Y
Set index to -0
SNAPOUT
Set THETAD to 0
SHTDN Flag Set?
Y
N
CDUX Flag Set?
N
Y
ENDMANU
NEWPHASE
(Restart Inhibit -2. 1)
ENDOFJOB
Set ENTRY Flag
NEWPHASE
(Restart Inhibit -3. 1)
ENDOFJOB
ROLL Flag Set?
N
Y
Set index to -2
CDUX Flag Set?
N
Y
Set index to -4
JUMP 7
COAST Flag Set?
N
Y
JUMP 6
TABT Flag Set?
N
Y
ENDMANU
NEWPHASE
(Restart Inhibit -2. 1)
ENDOFJOB
SETDTH
Store DTH as DTHETA
ENDOFJOB
(ATTIJOB2 exits here)
Call DOMANU in 0. 01 sec
Set VERT Flag
NEWMODE
Set Major Mode to local vertical
NEWPHASE
(Restart Inhibit -2. 1)
ENDOFJOB
Call ATTCNOFF in 0. 01 sec
Set VGCNTR to 2 for 3 passes thru CALCVGB for Δ error compt.
NEWPHASE
(Restart Inhibit -2. 1)
ENDOFJOB
0. 01 sec
ATTCNOFF
ENGINEON (TABT)
ENDOFJOB
N
SPS1 Flag Set?
Y
0. 01 sec
DOMANU
PHASCHNG
(Restart 5. 2)
ENDOFJOB
0. 01 sec
DOMANU


DOMANU
Set DOMAN Flag
DOMANU1
CALC Flag Set?
N
DOMANOFF
Remove DOMAN Flag
TASKOVER
Y
Call DOMANU
in TPAD +1 sec
N
DOMAN Flag Set
TASKOVER
TPAD + 1 (0) sec
DOMANU
Y
SETMANU
Establish MANUJOB
Call DOMANU1
in 0.5 sec
TASKOVER
MANUJOB
DTHETA > THETAMAN?
Y
JUMP 4
Store THETAMAN
as DTHETA
Remove DOMAN Flag
N
Store - (DTHETA - THETAMAN)
as THETAMAN
DRIVECDU
(Compute incremental maneuver)
Do CDUDRIVE
(Compute Δ CDU's
& Increment THETAD's)
DOMAN Flag Set?
Y
ENDOFJOB
0.5 sec
DOMANU1
DOMANU
N
MANUEXIT
Remove CALC Flag
Y
SPS1 Flag Set?
NEWPHASE
(Restart Inhibit -2, 1)
ENDOFJOB
0.5 sec
DOMANU1
DOMANU
N
NEXTMAN
Establish ATTIJOB2
(Computes next maneuver)
ENDOFJOB
ATTIJOB2
ATTIJOB
0.5 sec
DOMANU1
DOMANU


ENGINEON
GIMPOWON
Set SCS gim. mtr. powr. discrete
NEWPHASE
(Restart 4.24)
Store - TIME 1 as TBASE4
NEWPHASE
(Restart 4.25)
Call ATTCNOFF in 3.5 sec
TASKOVER
3.5 sec
ATTCNOFF
NEWPHASE
(Restart 4.18)
Store - TIME 1 as TBASE 4
Remove SCS att. cont. discrete
NEWPHASE
(Restart 4.19)
Call DVMODEON in 0.25 sec
TASKOVER
0.25 sec
DVMODEON
Set SCS ΔV mode discrete
NEWPHASE
(Restart 4.20)
Call ENGINEON in 0.25 sec
TASKOVER
0.25 sec
ENGINEON
Set DVCNTR neg.
Set engine on
Do READTIME
Store as TENGON
Set DVMON & STEER Flag
SPS1 Flag Set?
Y
Call PLUSXOFF in 15 sec
NEWPHASE
(Restart 4.21)
CALCMANU Finished?
N
NEWPHASE
(Restart Inhibit -2.1)
Establish ENEMA
(Force a Programmed Restart)
TASKOVER
ENEMA
(Cleans out EXECUTIVE & WAITLIST & Re-sets TASKS & JOBS)
Y
N
3 or 4 TEST
SPS3 or SPS4 Flag Set?
Y
NEWPHASE
(Restart 4.23)
Call ENGINOFF in 3 sec
Remove STEER Flag
TASKOVER
3 sec
ENGINOFF
(SPS3 and 4)
N
TUMTEST2
ARRST Flag Set?
Y
STR4OUT
Remove STEER Flag
TASK4OUT
NEWPHASE
(Restart Inhibit -4.1)
TASKOVER
N
NEWPHASE
(Restart 4.22)
ROLLTASK
STEER Flag Set?
N
TASKOVER
Y
Establish ROLLJOB
Call ROLLTASK in 5 sec
TASKOVER
Do ROLLJOB
(Maintains wings level via TVC)
ROLLEXIT
STEER Flag Set?
N
ENDOFJOB
Y
SPS2 Flag Set?
Y
SPS2MODE
NEWMODE
Set Major Mode to SPS 2
ENDOFJOB
N
SPS1 Flag Set?
N
ENDOFJOB
NEWMODE
Set Major Mode to SPS 1
ENDOFJOB
5 sec
ROLLTASK
ENGINEON
10 sec
PLUSXOFF
Remove scs + x trans. discrete
TASKOVER
(Called only once, 15 secs after SPS1 engine on!)

(Rev. 3 - 2/66)


STRTEST
ENDSERV (See Note)
N
STEER Flag Set?
Y
Do CALCVGB
(Computes VG & B)
(Exits to SHUTDOWN if fail to compute ABORT VR; VRFAIL)
PHASCHNG
(Restart 5. 5)
Zero ERRORSUM (on last pass)
Store MDTINIT as MDT & MDT + 1
Decrement VGCNTR
ENDSERV (See Note)
N
VGCNTR = Zero?
Y
JUMP 10
Remove CALC Flag
Store UNIT [CBDT-KPIP (DELV)] as UNITMDT
Store abval UNIT MDT as 30 & 31D
UNITMDT · VG
VG Decreasing?
N
VGALARM
Set ALARM
SHUTDOWN
Establish ENEMA
Set TIME 3 to 1
NEWPHASE
(Restart Inhibit -4. 1)
NEWPHASE
(Restart Inhibit -2. 1)
NEWPHASE
(Restart 3. 10)
ENDSERV
(See Note)
ENEMA
(Cleans out EXECUTIVE & WAITLIST, recalls READACCS, & establishes SHUTJOB)
Do SHUTJOB
(Set up for entry)
Y
Store UNITMDT · VG as 26D
30D + MDT
1. 523 (30D+ MDT) + 26D
Store as 26D
Y
SPS2 Flag Set?
N
JUMP 9
0. 995 (8) (26D)
STEERLAW
Store 30D as MDT
K1STEER (DELTAT)
[K1STEER (DELTAT) VG/VG] x UNITMDT
(STEERING cross-product)
Store as STEEROR
K2STEER (STEEROR) + ERRORSUM
Y
OVERFLOW?
N
Store above as ERRORSUM
N
ABVAL of above -ERRORMAX >0?
Y
SUMPOINT
STEERROR + ERRORSUM
CDU DRIVE
(Compute Δ CDU's & Increment THETAD's)
STREXIT
Attempt to grab display for VG
ENDSERV
(See Note)
0. 995 (8) (26D)/[30D + MDT]
Y
OVERFLOW
N
[0. 995 (8)(26D)/30D + MDT] DELTAT
SETTGO
Shift RT. & Compl.
N
STEER Flag Set?
Y
Store MPAC as LONGTIME
Store - TIME 1 as TBASE4
Compute time to go
Call ENGINOFF in above sec
PHASCHNG
(Restart 4. 1)
Remove STEER Flag
PHASCHNG
(Restart 4. 2)
ENDSERV
(See Note)
NOTE:
ENDSERV
DELTAT + 1 = 1?
N
Set DELTAT to 2 sec
Y
Set DELTAT to 2. 5 sec
Set 1/PIPADT to 2 (DELTAT)
PHASCHNG
(Restart 5. 1)
ENDOFJOB
? sec
ENGINOFF
(Only for SPS1, SPS2, ABRT, & TABT)


ENGINOFF
Set engine off
Do READTIME
Store as TCUTOFF
Remove DVMON Flag
Store PIPA X, Y, Z in VAVEGON, +1, +2
ARRST Flag Set?
Y
N
Set VGCNTR to 1 for 2 passes thru CALCVGB
Set INIT and INTP Flags
Set VRCADR to ABORTLOC
NEWPHASE (Restart 3. 3)
Set burn switch to TABT
TASKOVER
SPS1TEST
NEWPHASE (Restart 4. 28)
Store - TCUTOFF +1 as TBASE3 & TBASE4
SPS1 Flag Set?
Y
N
Call COASTPHS in 10.5 sec
Call GIMPOWOF in 7 sec
NEWPHASE (Restart 3. 4)
NEWPHASE (Restart 4. 3)
Set burn switch to SPS2
TASKOVER
7 sec
GIMPOWOF
Call DVMODOFF in 3.5 sec
Remove SCS gim. mtr. power discrete
NEWPHASE (Restart 3. 5)
TASKOVER
3. 5 sec
Do COASTPHS
(Set up for coast and SPS2)
TASKOVER
0. 0 sec
DVMODOFF
Remove SCS ΔV mode discrete
NEWPHASE (Restart 3. 6)
Call ATTCONON in 0. 25 sec
TASKOVER
0. 25 sec
ATTCONON
Set SCS att cont discrete
TASK3OUT
NEWPHASE (Restart Inhibit -3. 1)
TASKOVER
SPS2TEST
SPS2 Flag Set?
Y
N
Call CGTASK in 0. 75 sec
Call GIMPOWON in 6 sec
NEWPHASE (Restart 3. 7)
NEWPHASE (Restart 4. 10)
Set burn switch to SPS3
TASKOVER
0. 75 sec
CGTASK
Establish CGJOB
Call GMPOFF3 in 1. 25 sec
NEWPHASE (Restart 3. 8)
TASKOVER
CGJOB
NEWMODE
Set major mode to SPS3 burn
(Adjust for CG shift during SPS2)
ENDOFJOB
1. 25 sec
GMPOFF3
Remove SCS gim. mtr. powr. discrete
TASK3OUT
NEWPHASE (Restart Inhibit -3. 1)
TASKOVER
4 sec
GIMPOWON
ENGINEON
(SPS3)
NEWPHASE (Restart 4. 14)
GMPON
Call GIMPOWON in 6 sec
Establish mode 44
Set burn switch to SPS4
TASKOVER
MODE44
NEWMODE
Set Major Mode to SPS4
ENDOFJOB
6 sec
GIMPOWON
ENGINEON
(SPS4)
SPS3TEST
SPS3 Flag Set?
Y
N
SETMOD23
Establish mode 23
NEWPHASE (Restart 3. 9)
NEWPHASE (Restart Inhibit -4. 1)
Remove SCS + X trans discrete
GMPOFF
Call GIMPOWOF in 7 sec
NEWPHASE (Restart 3. 4)
TASKOVER
MODE23
NEWMODE
Set major mode to att hold
ENDOFJOB
7 sec
GIMPOWOF
Call DVMODOFF in 3. 5 sec
Remove SCS gim. mtr. powr. discrete
NEWPHASE (Restart 3. 5)
TASKOVER
3. 5 sec
DVMODOFF
Remove SCS ΔV mode discrete
NEWPHASE (Restart 3. 6)
Call ATTCONON in 0. 25 sec
TASKOVER
0. 25 sec
ATTCONON
Set SCS att cont discrete
TASK3OUT
NEWPHASE (Restart Inhibit -3. 1)
TASKOVER
NOTE:
COASTPHS interrupted for DVMODOFF and ATTCONON

COASTPHS

Set COAST Flag

Set up LONGCALL
with 289.5 sec

Store FDAILOC (FDAONTSK)
in CALLCADR

Establish VERTINIT

NEWPHASE
(Restart 2.2)

NEWPHASE
(Restart 4.4)

TASKOVER

Do VERTINIT
(Set Major Mode to
maneuver to local vert;
Compute & store desired
post SPS1 S/C attitude)

Do ATTIJOB1

(Maneuver to vertical
coast phase attitude)

289.5 sec

FDAONTSK
Set SCS FDAI align discrete

Call FDAOFTSK
in 10 sec

NEWPHASE
(Restart 4.5)

TASKOVER

10 sec

FDAOFTSK

Set up LONGCALL
with (TCOAST - 310 sec)

Store UPTSKLOC (UPTASK)
in CALLCADR

NEWPHASE
(Restart 4.6)

FDOFTSK1

Remove SCS FDAI align discrete

TASKOVER

TCOAST (3114)
- 310 sec

UPTASK

Call PRE+X2
in 18 sec

Establish UPJOB

NEWPHASE
(Restart 4.7)

Store - TIME 1
as TBASE4

NEWPHASE
(Restart Inhibit -5.1)

NEWPHASE
(Restart 4.8)

TASKOVER

UPJOB

NEWMODE
Revert to att
hold mode with no V76

Store LDNLST1
in DNLSTADR

UPDATFLG Set?

Y:

Compute & Store DT for final
integ. as TAVEGON

(DT = (TCUTOFF
+ TCOAST + 20
-(STBUFF + 12D))

AVETOMD2
(See Note)

(202 ORBTL. INTEG)

Store RAVEGON &
VAVEGON as RN & VN

Do CALCGRAV

(Set up initial
corrected gravity)

N:

NOSTATE

PHASCHNG
(Restart 4.9)

JAMTERM
Flush out V76)

ENDOFJOB

18 sec

PRE+X2

Call PLUSX2
in 2 sec

Remove UPDAT FLG

NEWPHASE
(Restart 4.27)

TASKOVER

2 sec

PLUSX2

PIPASR

(Read PIPAS, store in
DELV, & zero PIPA Cntrs)

Call GIMPOWON
in 26 sec

Set SCS+X
trans. discrete

Remove DRIFT Flag

Store-PIPTIME+1
as TBASE5

NEWPHASE
(Restart 5.6)

NEWPHASE
(Restart 4.17)

Call READACCS
in 2 sec

Establish MODE32

TASKOVER

MODE 32

NEWMODE

Set Major Mode
to PRE-SPS2

Set INTP Flag

Store PIPTIME + 1
in MPAC

POSTJUMP to
LASTBIAS

LASTBIAS

(Prepare for reading
PIPA's)

ENDOFJOB

2 sec

READACCS

(Read PIPA's)

TASKOVER

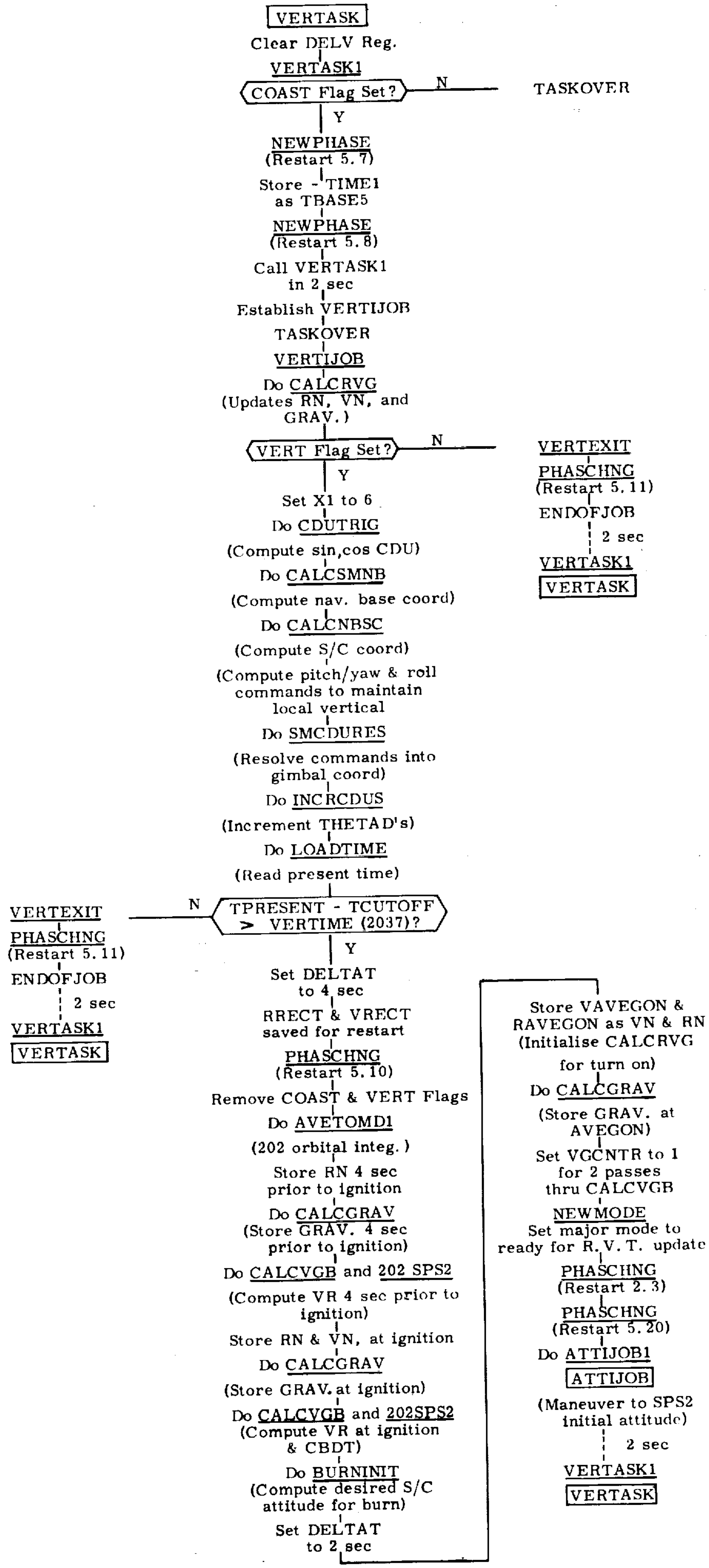
24 sec

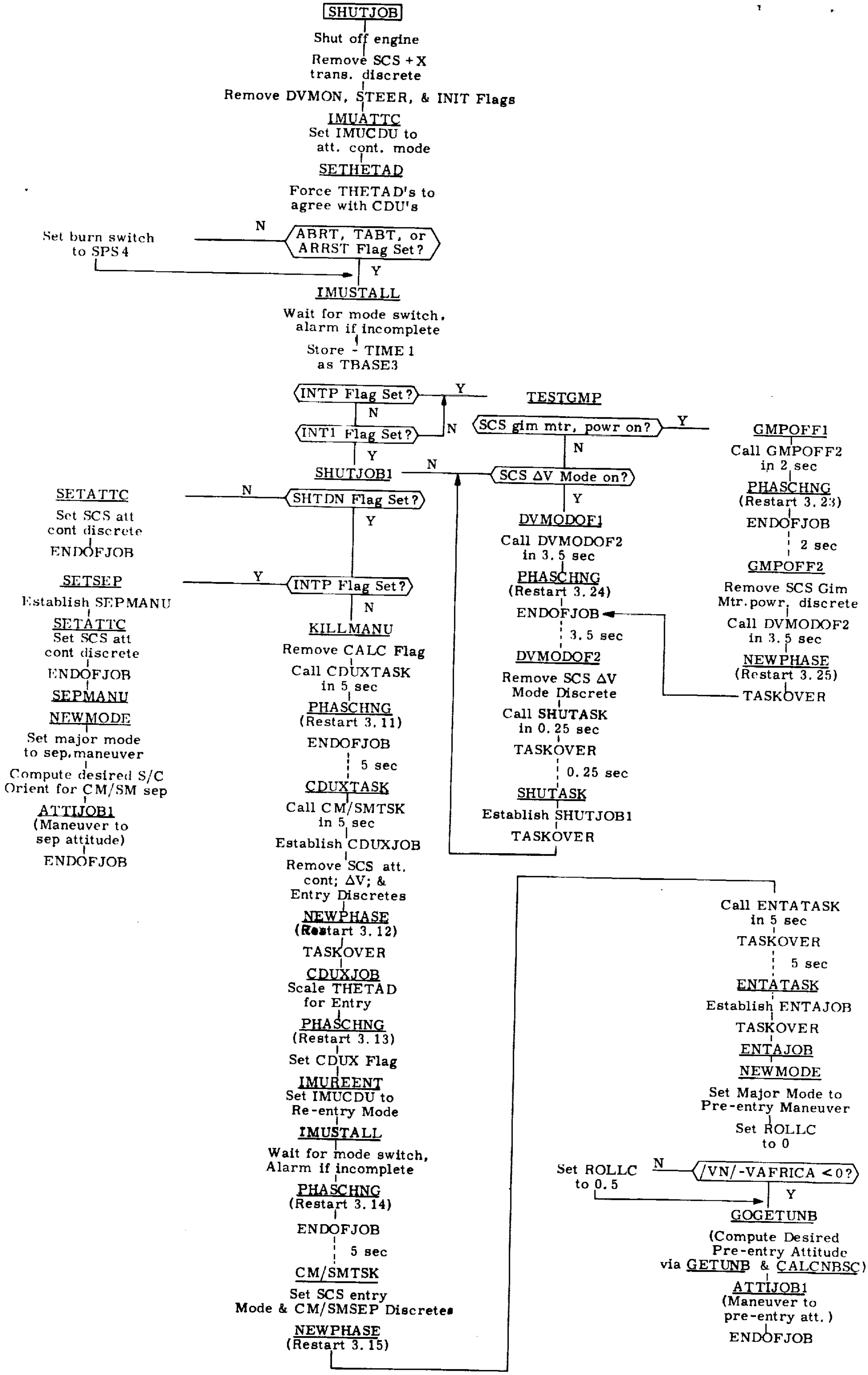
GIMPOWON

ENGINEON

(SPS2)

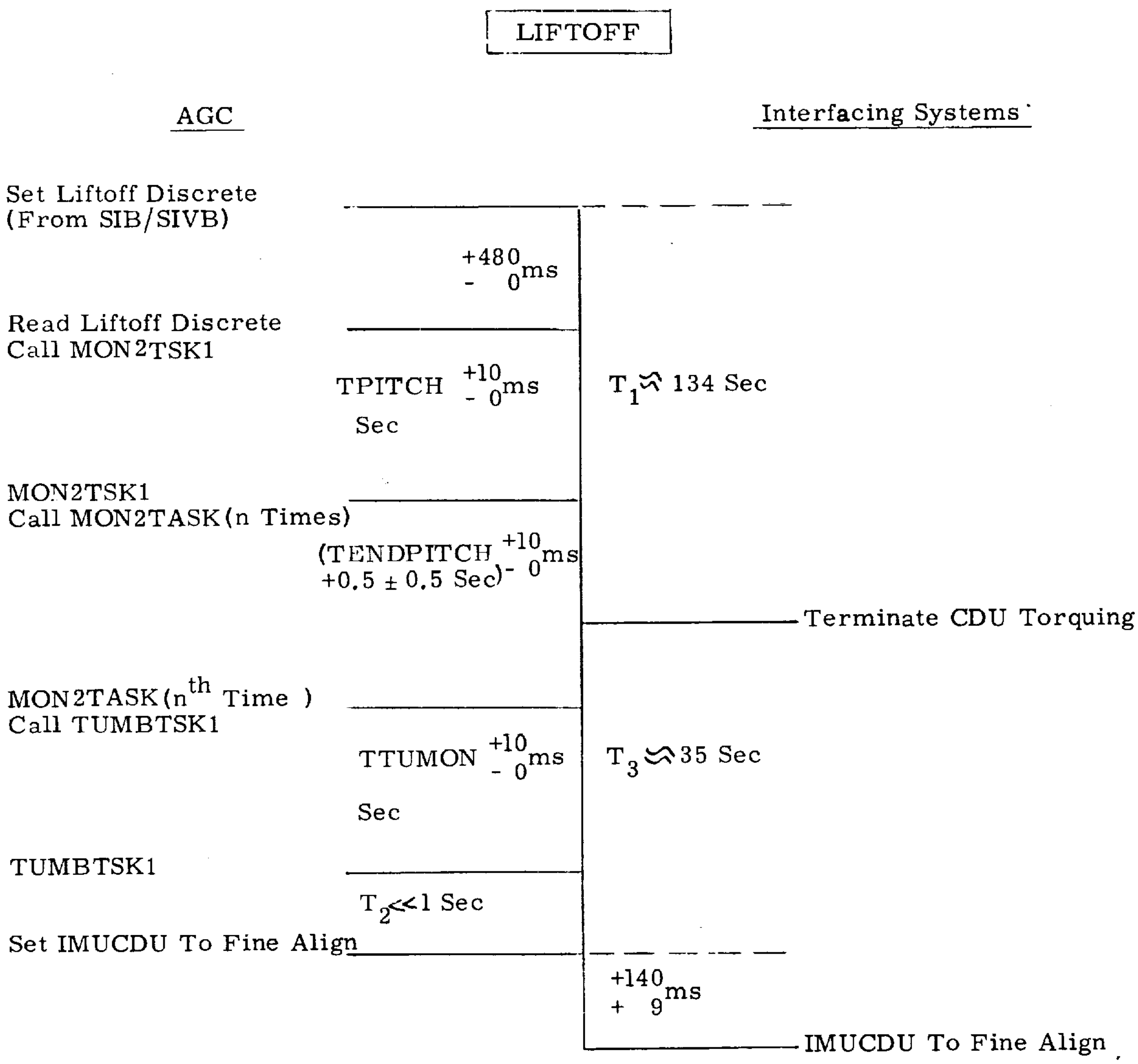
NOTE:
If AVETOMD2 not finished by the time PRE+X2 is reached, PRE+ X2 kills i by removing UPDATFLG!


VERTASK
Clear DELV Reg.
VERTASK1
COAST Flag Set?
N
TASKOVER
Y
NEWPHASE
(Restart 5.7)
Store - TIME1
as TBASE5
NEWPHASE
(Restart 5.8)
Call VERTASK1
in 2 sec
Establish VERTIJOB
TASKOVER
VERTIJOB
Do CALCRVG
(Updates RN, VN, and
GRAV.)
VERT Flag Set?
N
VERTEXIT
PHASCHNG
(Restart 5.11)
ENDOFJOB
2 sec
VERTASK1
VERTASK
Y
Set X1 to 6
Do CDUTRIG
(Compute sin,cos CDU)
Do CALCSMNB
(Compute nav. base coord)
Do CALCNBSC
(Compute S/C coord)
(Compute pitch/yaw & roll
commands to maintain
local vertical
Do SMCDURES
(Resolve commands into
gimbal coord)
Do INCRCDUS
(Increment THETAD's)
Do LOADTIME
(Read present time)
TPRESENT - TCUTOFF
> VERTIME (2037)?
N
VERTEXIT
PHASCHNG
(Restart 5.11)
ENDOFJOB
2 sec
VERTASK1
VERTASK
Y
Set DELTAT
to 4 sec
RRECT & VRECT
saved for restart
PHASCHNG
(Restart 5.10)
Remove COAST & VERT Flags
Do AVETOMD1
(202 orbital integ.)
Store RN 4 sec
prior to ignition
Do CALCGRAV
(Store GRAV. 4 sec
prior to ignition)
Do CALCVGB and 202 SPS2
(Compute VR 4 sec prior to
ignition)
Store RN & VN, at ignition
Do CALCGRAV
(Store GRAV. at ignition)
Do CALCVGB and 202SPS2
(Compute VR at ignition
& CBDT)
Do BURNINIT
(Compute desired S/C
attitude for burn)
Set DELTAT
to 2 sec
Store VAVEGON &
RAVEGON as VN & RN
(Initialise CALCRVG
for turn on)
Do CALCGRAV
(Store GRAV. at
AVEGON)
Set VGCNTR to 1
for 2 passes
thru CALCVGB
NEWMODE
Set major mode to
ready for R.V.T. update
PHASCHNG
(Restart 2.3)
PHASCHNG
(Restart 5.20)
Do ATTIJOB1
ATTIJOB
(Maneuver to SPS2
initial attitude)
2 sec
VERTASK1
VERTASK


SHUTJOB
Shut off engine
Remove SCS +X trans. discrete
Remove DVMON, STEER, & INIT Flags
IMUATTC
Set IMUCDU to att. cont. mode
SETHETAD
Force THETAD's to agree with CDU's
ABRT, TABT, or ARRST Flag Set?
N
Set burn switch to SPS4
Y
IMUSTALL
Wait for mode switch, alarm if incomplete
Store - TIME 1 as TBASE3
INTP Flag Set?
Y
N
INT1 Flag Set?
N
Y
SHUTJOB1
SHTDN Flag Set?
N
SETATTC
Set SCS att cont discrete
ENDOFJOB
Y
INTP Flag Set?
Y
SETSEP
Establish SEPMANU
SETATTC
Set SCS att cont discrete
ENDOFJOB
SEPMANU
NEWMODE
Set major mode to sep. maneuver
Compute desired S/C Orient for CM/SM sep
ATTIJOB1
(Maneuver to sep attitude)
ENDOFJOB
N
KILLMANU
Remove CALC Flag
Call CDUXTASK in 5 sec
PHASCHNG
(Restart 3.11)
ENDOFJOB
5 sec
CDUXTASK
Call CM/SMTSK in 5 sec
Establish CDUXJOB
Remove SCS att. cont; ΔV; & Entry Discretes
NEWPHASE
(Restart 3.12)
TASKOVER
CDUXJOB
Scale THETAD for Entry
PHASCHNG
(Restart 3.13)
Set CDUX Flag
IMUREENT
Set IMUCDU to Re-entry Mode
IMUSTALL
Wait for mode switch, Alarm if incomplete
PHASCHNG
(Restart 3.14)
ENDOFJOB
5 sec
CM/SMTSK
Set SCS entry Mode & CM/SMSEP Discretes
NEWPHASE
(Restart 3.15)
TESTGMP
SCS gim mtr, powr on?
Y
N
SCS ΔV Mode on?
N
Y
DVMODOF1
Call DVMODOF2 in 3.5 sec
PHASCHNG
(Restart 3.24)
ENDOFJOB
3.5 sec
DVMODOF2
Remove SCS ΔV Mode Discrete
Call SHUTASK in 0.25 sec
TASKOVER
0.25 sec
SHUTASK
Establish SHUTJOB1
TASKOVER
GMPOFF1
Call GMPOFF2 in 2 sec
PHASCHNG
(Restart 3.23)
ENDOFJOB
2 sec
GMPOFF2
Remove SCS Gim Mtr. powr. discrete
Call DVMODOF2 in 3.5 sec
NEWPHASE
(Restart 3.25)
TASKOVER
Call ENTATASK in 5 sec
TASKOVER
5 sec
ENTATASK
Establish ENTAJOB
TASKOVER
ENTAJOB
NEWMODE
Set Major Mode to Pre-entry Maneuver
Set ROLLC to 0
/VN/-VAFRICA <0?
N
Set ROLLC to 0.5
Y
GOGETUNB
(Compute Desired Pre-entry Attitude via GETUNB & CALCNBSC)
ATTIJOB1
(Maneuver to pre-entry att.)
ENDOFJOB

4.2.1 Timing Tolerances:

Tolerances on the sequential timing of discrete events are listed below. Certain of these may change if the AGC program changes. The times are to receipt of the signal by the interfacing system (usually the DSKY), and are quoted from the preceding event unless otherwise noted. Times T_1-T_6 are not, specified as they are especially program dependent and difficult to predict.



S4BSMSEP

AGC			Interfacing Systems
Set S4BSMSEP Discrete (From MESC)			
	$^{+120}_{-0}$ ms	+ 249 ms + 4	
Read S4BSMSEP Discrete Set SCS +x Trans. ON Set SCS Att. Cont. ON Set SCS Gim. Mtr. Powr. ON Call ABRTWAIT			
	1.7 Sec $^{+10}_{-0}$ ms		SCS +x Trans. ON SCS Att. Cont. ON SCS Gim. Mtr. Powr. ON
ABRTWAIT Call SCS Att. Cont. OFF		$T_4 > 3.7$ Sec	(From S4BSMSEP)
	10.5 Sec $^{+10}_{-0}$ ms		Start Attn. Maneuver For SPS 1
Set SCS Attn Cont. OFF Call SPS ΔV Mode ON			
	0.25 Sec $^{+10}_{-0}$ ms		SCS Att. Cont. OFF
Set SCS ΔV Mode ON Call SPS 1 Engine ON		240 or 360 ± 6 ms	
	0.25 Sec $^{+10}_{-0}$ ms		SCS ΔV Mode ON
Set SPS 1 Engine ON Call SCS +x Trans. OFF		240 or 360 $^{-9}_{-4}$ ms	SPS 1 Engine ON
	15 Sec $^{+10}_{-0}$ ms	15000 $^{+139}_{+4}$ ms	
Set SCS +x Trans. OFF			
			SCS +x Trans. OFF

SPS 1 ENGINE OFF

AGC	AGC Timing	Interfacing Timing	Interfacing Systems
Set SPS 1 Engine OFF Call SCS Gim. Mtr. Powr. OFF			SPS 1 Engine OFF
	7 Sec $^{+10}_{-0}$ ms	7000 $^{+139}_{+\ 4}$ ms	
Set SCS Gim. Mtr. Powr. OFF Call SCS ΔV Mode OFF			
	3.5 Sec $^{+10}_{-0}$ ms		SCS Gim. Mtr. Powr. OFF
Set SCS ΔV Mode OFF Call SCS Att. Cont. ON		3480 or 3600 ± 6 ms	
	0.25 Sec $^{+10}_{-0}$ ms		SCS ΔV Mode OFF
Set SCS Att. Cont. ON		240 or 360 ± 6 ms	
			SCS Att. Cont. ON

SPS 1 ENGINE OFF

AGC	AGC Timing	Interfacing Timing	Interfacing Systems
Set SPS 1 Engine OFF Call COASTPHS			SPS 1 Engine OFF
	10.5 Sec $^{+10}_{-0}$ ms	$T_5 > 10$ Sec	
COASTPHS Call FDA I Align ON			
	289.5 Sec $^{+10}_{-0}$ ms		Start Att. Maneuver to Vertical
Set FDA I Align ON Call FDA I Align OFF		300,000 $^{+149}_{+\ 4}$ ms(From SPS 1 Engine OFF)	
	10 Sec $^{+10}_{-0}$ ms		FDA I Align ON
Set FDA I Align OFF Call Uptask		9960 or 10080 ± 6 ms	
	(TCOAST -310) Sec $^{+10}_{-0}$ ms		FDA I Align OFF
Uptask Call SCS +x Trans. ON			
	20 Sec $^{+10}_{-0}$ ms	f (TCOAST + 20 Sec) ± 6 ms	

SPS 1 ENGINE OFF

AGC	Timing	Interfacing Systems
Set SCS +x Trans. ON Call SCS Gim. Mtr. Powr. ON		
	26 Sec $^{+10}_{-0}$ ms	SCS +x Trans. ON
Set SCS Gim. Mtr. Powr. ON Call SCS Att. Cont. OFF	25920 or 26040 ± 6 ms	
	3.5 Sec $^{+10}_{-0}$ ms	SCS Gim. Mtr. Powr. ON
Set SCS Att. Cont. OFF Call SCS ΔV Mode ON	3480 or 3600 ± 6 ms	
	0.25 Sec $^{+10}_{-0}$ ms	SCS Att. Cont. OFF
Set SCS ΔV Mode ON Call SPS 2 Engine ON	240 or 360 ± 6 ms	
	0.25 Sec $^{+10}_{-0}$ ms	SCS ΔV Mode ON
	240 or 360 $^{-9}_{-4}$ ms	
Set SPS 2 Engine ON		SPS 2 ENGINE ON

SPS 2 ENGINE OFF

AGC	Timing	Interfacing Systems
Set SPS 2 Engine OFF Call SCS Gim. Mtr. Powr. OFF		SPS 2 Engine OFF
	2 Sec $^{+10}_{-0}$ ms	
	2000 $^{+139}_{+4}$ ms	
Set SCS Gim. Mtr. Powr. OFF		
		SCS Gim. Mtr. Powr. OFF

SPS 2 ENGINE OFF

AGC			Interfacing Systems
Set SPS 2 Engine OFF Call SCS Gim. Mtr. Powr. ON			SPS 2 Engine OFF
	6 Sec $^{+10}_{-0}$ ms	6000 $^{+139}_{+4}$ ms	
Set SCS Gim. Mtr. Powr. ON Call SCS Att. Cont. OFF			
	3.5 Sec $^{+10}_{-0}$ ms		SCS Gim. Mtr. Powr. ON
Set SCS Att. Cont. OFF Call SCS ΔV Mode ON			
	0.25 Sec $^{+10}_{-0}$ ms	3960 or 4080 $\begin{matrix}-9\\-4\end{matrix}$ ms	
Set SCS ΔV Mode ON Call SPS 3 Engine ON			
	0.25 Sec $^{+10}_{-0}$ ms		
Set SPS 3 Engine ON Call SPS 3 Engine OFF			SPS 3 Engine ON
	3 Sec $^{+10}_{-0}$ ms	3000 $^{+10}_{-0}$ ms	
Set SPS 3 Engine OFF Call SCS Gim. Mtr. Powr. ON			SPS 3 Engine OFF
	6 Sec $^{+10}_{-0}$ ms		
Set SCS Gim. Mtr. Powr. ON Call SCS Att. Cont. OFF			
	3.5 Sec $^{+10}_{-0}$ ms		
Set SCS Att. Cont. OFF Call SCS ΔV Mode ON		10000 $^{+40}_{-0}$ ms	
	0.25 Sec $^{+10}_{-0}$ ms		
Set SCS ΔV Mode ON Call SPS 4 Engine ON			
	0.25 Sec $^{+10}_{-0}$ ms		
Set SPS 4 Engine ON Call SPS 4 Engine OFF			SPS 4 Engine ON
	3 Sec $^{+10}_{-0}$ ms	3000 $^{+10}_{-0}$ ms	
Set SPS 4 Engine OFF Set SCS +x Trans. OFF Call SCS Gim. Mtr. Powr. OFF			SPS 4 Engine OFF
	7 Sec $^{+10}_{-0}$ ms	$^{+129}_{+4}$ ms	SCS +x Trans. OFF

SPS 2 ENGINE OFF

AGC

Set SCS Gim. Mtr. Powr. OFF
Call SCS ΔV Mode OFF

3.5 Sec $^{+10}_{-0}$ ms

Set SCS ΔV Mode OFF
Call SCS Att. Cont. ON

0.25 Sec $^{+10}_{-0}$ ms

Set SCS Att. Cont. ON

Interfacing Systems

6960 or 7080 $\pm$ 6 ms (From SPS Engine OFF)

SCS Gim. Mtr. Powr. OFF

3480 or 3600 $\pm$6 ms

SCS ΔV Mode OFF

240 or 360 $\pm$6 ms

SCS Att. Cont. ON

CM/SM SEP

AGC

Call CDUX TASK

5 Sec $^{+10}_{-0}$ ms

CDUX TASK
Call CM/SM TSK

5 Sec $^{+10}_{-0}$ ms

Set SCS Entry ON
Set CM/SM Sep. ON

Interfacing Systems

10000 $^{+149}_{+4}$ ms

SCS Entry ON
CM/SM Sep. ON

CM/SM SEP

AGC

Interfacing Systems

Call CDUX TASK

5 Sec $^{+10}_{-0}$ ms

CDUX TASK
Establishing CDUX JOB

$T_6 \ll 1$ Sec

$f(T_6 + 5 \text{ Sec})\ ^{+129}_{+4}$ ms

Set SCS Monitor (no) Mode ON
(SCS Att. Cont. OFF)

SCS Monitor (no) Mode ON
(SCS Att. Cont. OFF)

0.05 G SENSED

Set 0.05 G Ind. ON

$^{+129}_{+\ 4}$ ms

0.05 G Ind. ON

4.3 Nominal Mission Timeline

The nominal mission timeline is presented in the following diagrams.

Column #1 (TIME) refers all events to T_o, the time of " LIFTOFF" signal generation. Major event times are from the spacecraft reference trajectory where available. Tracking coverage times are also from reference trajectory data assuming a tracking elevation angle greater than 5^o and a tracking range less than 1000 n. m. Those events not specifically defined in time by the reference trajectory and under the control of the AGC are indicated by an asterisk (*), and are from MIT All-Digital Simulation #340971. These times refer only to that simulation but will vary only slightly each time the AGC performs the sequence.

Columns #2 and #3 (SUBSEQUENCE ΔT) give design-center times for various subsequences throughout the mission. These times are subject to the operating tolerances of the equipment controlling the subsequence.

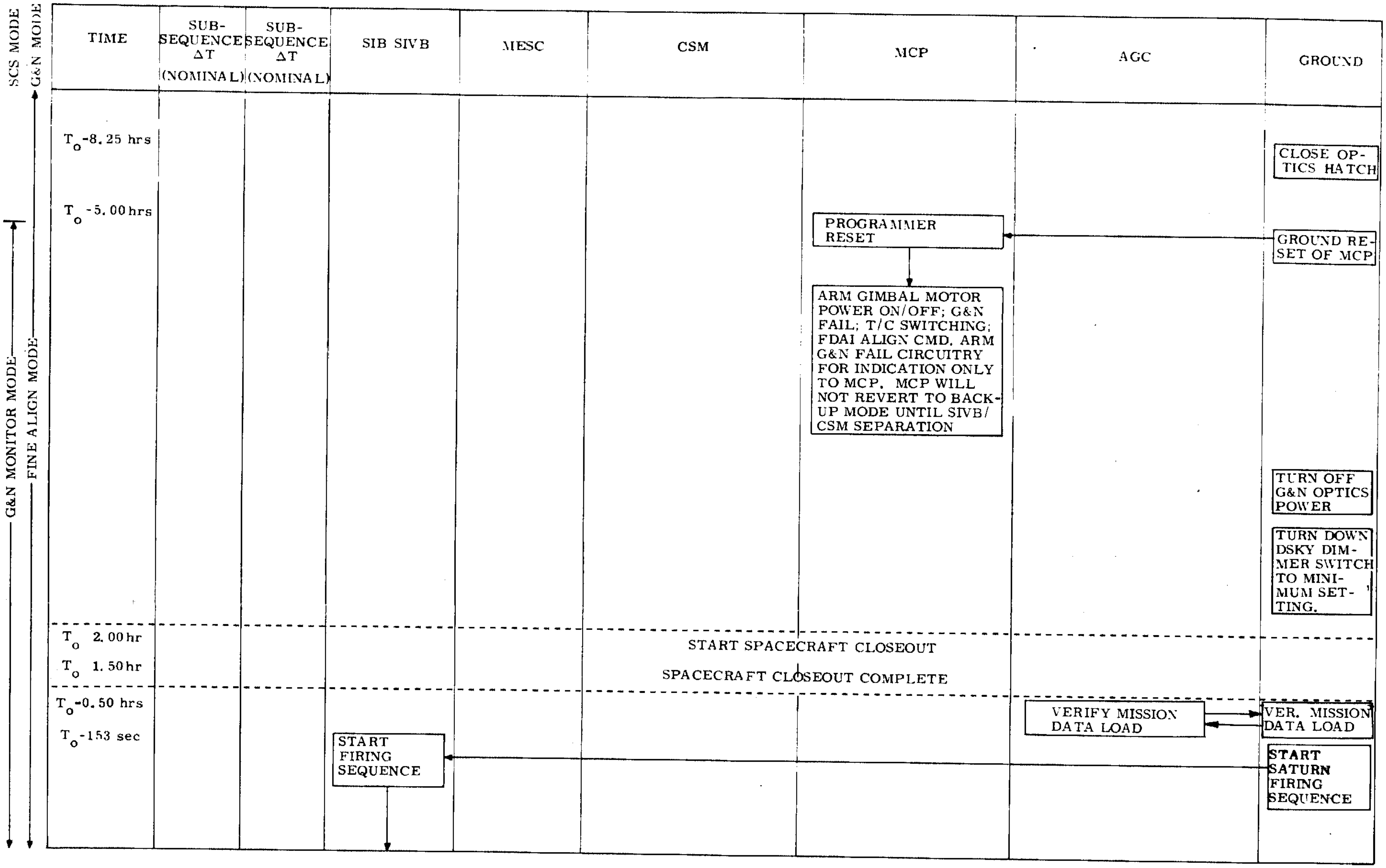
NORMAL SEQUENCE OF EVENTS - MISSION 202
S/C 011/ MISSION CONTROL PROGRAMMER / G&N

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
					PRELAUNCH			
T_o-12.50 hrs							TURN ON G&N → ENABLE UPLINK	
T_o-12.00 hrs							"FRESH START" OF AGC → LOAD MISSION DATA (A) IMU PARAMETERS (B) LAUNCH SITE VECTORS (C) POWERED FLIGHT PARAMETERS (D) OPTICAL TARGETS (E) BOOST MONITOR POLYNOMIALS	LOAD MISSION DATA VIA ACE
T_o-11.25 hrs							AGC CLOCK ALIGNMENT	GROUND SYNCHRONIZATION OF AGC TIME THRU ACE
T_o-10.75 hrs							G&N STARTS GYROCOMPASSING MODE FOR IMU ALIGNMENT TO LAUNCH AZIMUTH. SET FINE ALIGN MODE IN G&N	
T_o-10.50 hrs							OPTICS SIGHTING TO VERIFY GYROCOMPASSING	
T_o-9.00 hrs							REPEAT OPTICS SIGHTING TO VERIFY GYROCOMPASSING	

SCS MODE

G&N MODE

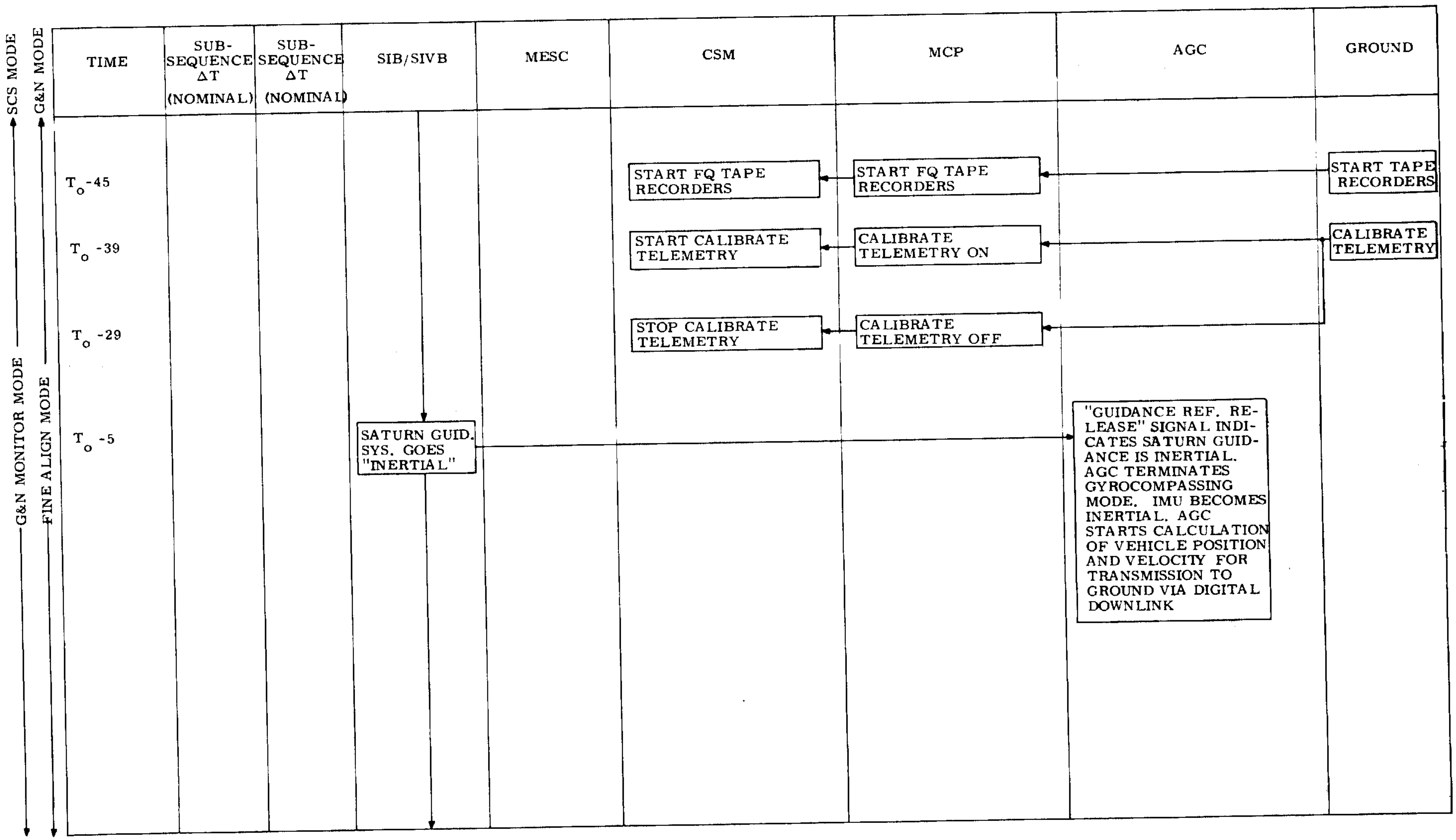
FINE ALIGN MODE



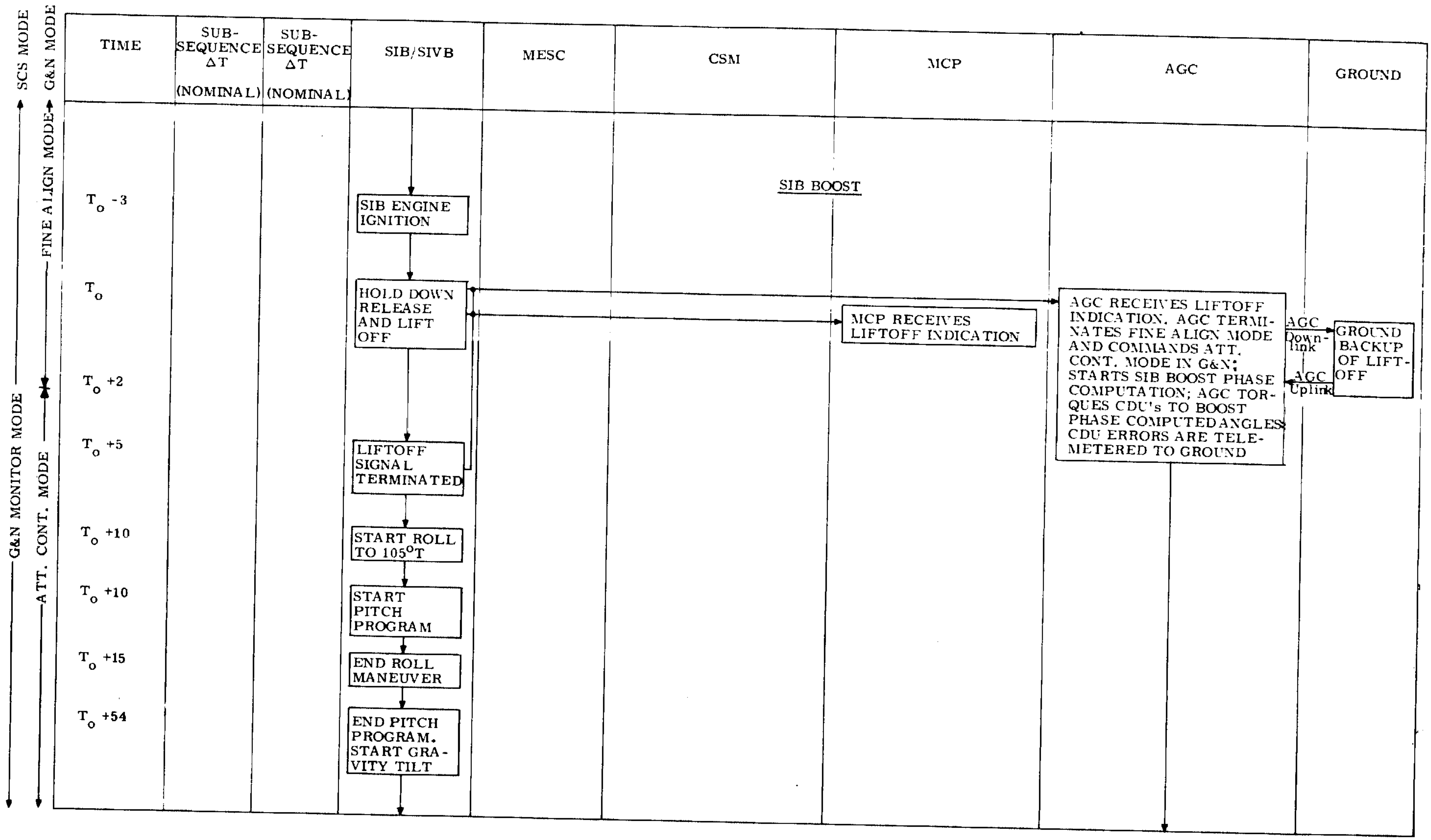
TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB SIVB	MESC	CSM	MCP	AGC	GROUND
T_o-8.25 hrs								CLOSE OPTICS HATCH
T_o-5.00 hrs						PROGRAMMER RESET		GROUND RESET OF MCP
						ARM GIMBAL MOTOR POWER ON/OFF; G&N FAIL; T/C SWITCHING; FDAI ALIGN CMD. ARM G&N FAIL CIRCUITRY FOR INDICATION ONLY TO MCP. MCP WILL NOT REVERT TO BACK-UP MODE UNTIL SIVB/CSM SEPARATION		
								TURN OFF G&N OPTICS POWER
								TURN DOWN DSKY DIMMER SWITCH TO MINIMUM SETTING.
T_o 2.00 hr					START SPACECRAFT CLOSEOUT			
T_o 1.50 hr					SPACECRAFT CLOSEOUT COMPLETE			
T_o-0.50 hrs							VERIFY MISSION DATA LOAD	VER. MISSION DATA LOAD
T_o-153 sec			START FIRING SEQUENCE					START SATURN FIRING SEQUENCE

SCS MODE: G&N MONITOR MODE

G&N MODE: FINE ALIGN MODE



SCS MODE
G&N MODE
G&N MONITOR MODE
FINE ALIGN MODE
TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
T o -45
T o -39
T o -29
T o -5
START FQ TAPE RECORDERS
START FQ TAPE RECORDERS
START TAPE RECORDERS
START CALIBRATE TELEMETRY
CALIBRATE TELEMETRY ON
CALIBRATE TELEMETRY
STOP CALIBRATE TELEMETRY
CALIBRATE TELEMETRY OFF
SATURN GUID. SYS. GOES "INERTIAL"
"GUIDANCE REF. RELEASE" SIGNAL INDICATES SATURN GUIDANCE IS INERTIAL. AGC TERMINATES GYROCOMPASSING MODE. IMU BECOMES INERTIAL. AGC STARTS CALCULATION OF VEHICLE POSITION AND VELOCITY FOR TRANSMISSION TO GROUND VIA DIGITAL DOWNLINK



TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
SIB BOOST
T0 -3
T0
T0 +2
T0 +5
T0 +10
T0 +10
T0 +15
T0 +54
SIB ENGINE IGNITION
HOLD DOWN RELEASE AND LIFT OFF
LIFTOFF SIGNAL TERMINATED
START ROLL TO 105°T
START PITCH PROGRAM
END ROLL MANEUVER
END PITCH PROGRAM. START GRAVITY TILT
MCP RECEIVES LIFTOFF INDICATION
AGC RECEIVES LIFTOFF INDICATION. AGC TERMINATES FINE ALIGN MODE AND COMMANDS ATT. CONT. MODE IN G&N; STARTS SIB BOOST PHASE COMPUTATION; AGC TORQUES CDU's TO BOOST PHASE COMPUTED ANGLES. CDU ERRORS ARE TELEMETERED TO GROUND
AGC Down-link
AGC Uplink
GROUND BACKUP OF LIFT-OFF
SCS MODE
G&N MONITOR MODE
G&N MODE
FINE ALIGN MODE
ATT. CONT. MODE

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
T_o +77			MAXIMUM DYNAMIC PRESSURE					
T_o +136							AGC TERMINATES SIB BOOST MONITOR PHASE COMPUTATION: AGC STOPS TORQUING CDU'S AND HOLDS THEM AT CONSTANT ANGLES. AGC CONTINUES MONITOR OF VEHICLE POSITION AND VELOCITY FOR SIVB BURN: THIS IS SOLE OBLIGATION OF G&N FOR SIVB BOOST MONITOR.	
T_o +138			STOP GRAVITY TILT					
T_o +140.25			INBOARD ENGINE CUT-OFF					
T_o +146.25			OUTBOARD ENGINE CUT-OFF					
T_o +148.65			ENGINE THRUST TERMINATION					

SCS MODE ← G&N MONITOR MODE →

G&N MODE ← ATT. CONT. MODE →

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
					SIB/SIVB SEPARATION & SIVB BOOST			
			SIB/SIVB SEPARATION					
T_o+151.75			SIVB ENGINE IGNITION					
T_o+154.85			SIVB ENGINE REACHES FULL THRUST					
T_o+161.75			SIVB J2 ENGINE MIXTURE RATIO SHIFT					
T_o +169.11							AGC COMMANDS G&N SYSTEM TO FINE ALIGN MODE IN READINESS FOR POSSIBLE ABORT. AGC COMMENCES MONITOR OF VEHICLE RATES FOR TUMBLING DETECTION BY MONITORING IMU GIMBAL ANGLE RATES OF CHANGE	
T_o+171.75			COMMAND LET JETTISON			START LET JETTISON SEQUENCE		
			JETTISON ULLAGE RKT. CASES	START LET JETTISON SEQUENCE		COMMAND LET JETTISON		
				DISABLE AUTO FUNCTION EDS		COMMAND FQ TAPE RECORDER OFF		

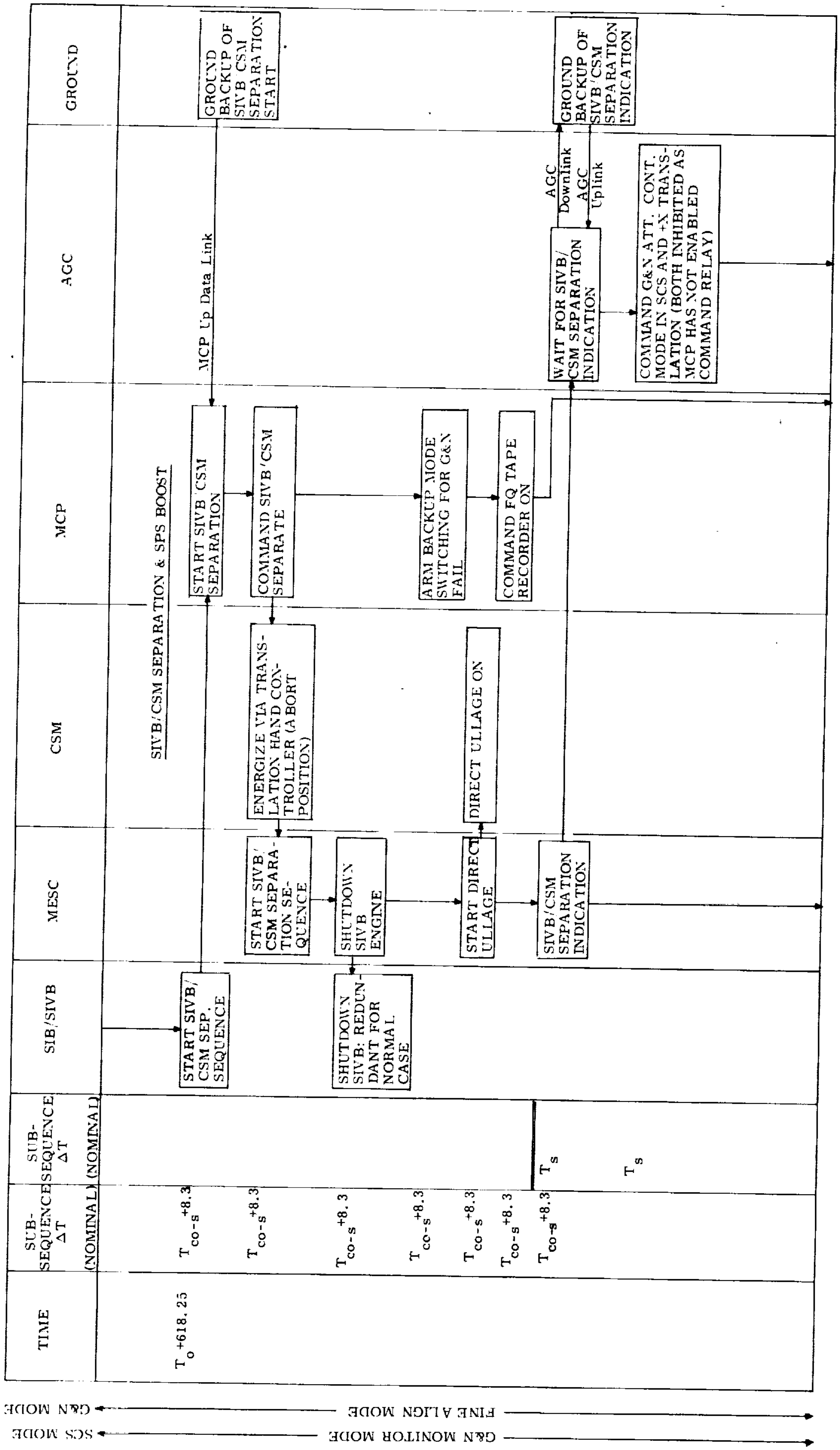
SCS MODE ← G&N MONITOR MODE →

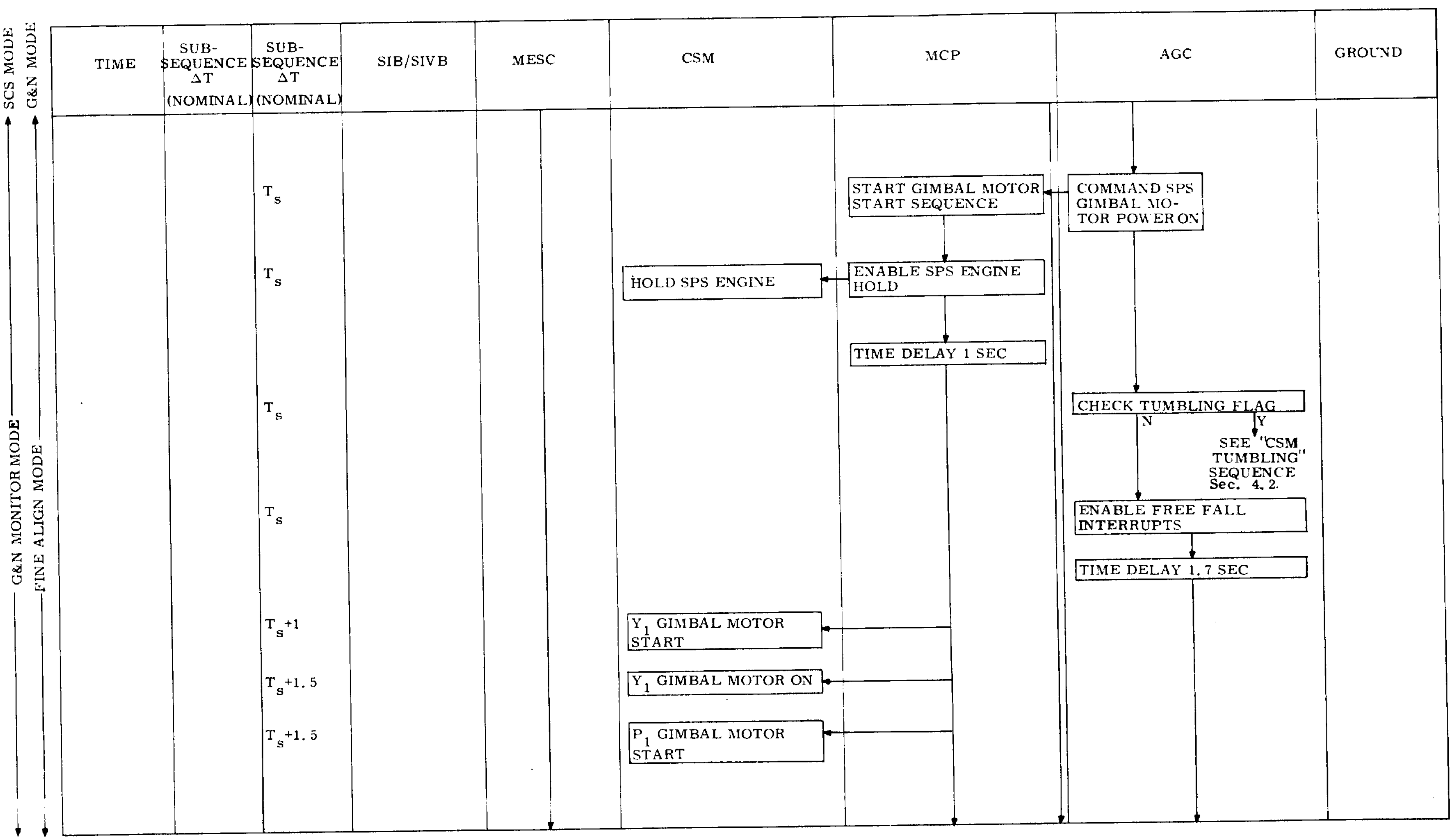
G&N MODE ← ATT. CONT. MODE | FINE ALIGN MODE →

SCS MODE ← G&N MONITOR MODE →

G&N MODE ← FINE ALIGN MODE →

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
				SELECT SPS ABORT MODE LOGIC IN MESC				
				FIRE TOWER BOLTS				
T_o+172.25				FIRE JETTISON MOTOR		BACKUP IGNITION OF LAUNCH ESCAPE MOTOR SHOULD JETTISON MOTOR NOT HAVE FIRED (ASSUMES BOLTS HAVE SEPARATED)		
T_o+451.75			SIVB J2 ENGINE MIXTURE RATIO SHIFT					
T_o+560								TRACKING ACQUIRED BY ANTIGUA LAT 17° 08' 36"N LONG 61° 47' 33" W
T_o+609.95	T_{co-s}		GUIDANCE SHUTDOWN OF SIVB					
	T_{co-s}		SIVB GOES TO RATE STABILIZATION MODE WITH ZERO RATE COMMAND					
	T_{co-s}+1.5		SIVB THRUST TAIL OFF COMPLETE					
	T_{co-s}+1.5		ADAPTER FOLD BACK COMPLETE					


GROUND
AGC
MCP
CSM
MESC
SIB/SIVB
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
TIME
SIVB/CSM SEPARATION & SPS BOOST
T_o +618.25
T_{co-s} +8.3
T_{co-s} +8.3
T_{co-s} +8.3
T_{co-s} +8.3
T_{co-s} +8.3
T_{co-s} +8.3
T_{co-s} +8.3
T_s
T_s
START SIVB/ CSM SEP. SEQUENCE
START SIVB/CSM SEPARATION
MCP Up Data Link
GROUND BACKUP OF SIVB CSM SEPARATION START
COMMAND SIVB/CSM SEPARATE
ENERGIZE VIA TRANSLATION HAND CONTROLLER (ABORT POSITION)
START SIVB/ CSM SEPARATION SEQUENCE
SHUTDOWN SIVB ENGINE
SHUTDOWN SIVB: REDUNDANT FOR NORMAL CASE
ARM BACKUP MODE SWITCHING FOR G&N FAIL
START DIRECT ULLAGE
DIRECT ULLAGE ON
COMMAND FQ TAPE RECORDER ON
SIVB/CSM SEPARATION INDICATION
WAIT FOR SIVB/ CSM SEPARATION INDICATION
AGC Downlink
AGC Uplink
GROUND BACKUP OF SIVB/CSM SEPARATION INDICATION
COMMAND G&N ATT. CONT. MODE IN SCS AND +X TRANSLATION (BOTH INHIBITED AS MCP HAS NOT ENABLED COMMAND RELAY)
G&N MODE ← FINE ALIGN MODE →
SCS MODE ← G&N MONITOR MODE →


TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
COMMAND SPS GIMBAL MO-TOR POWER ON
START GIMBAL MOTOR START SEQUENCE
ENABLE SPS ENGINE HOLD
HOLD SPS ENGINE
TIME DELAY 1 SEC
CHECK TUMBLING FLAG
N
Y
SEE "CSM TUMBLING" SEQUENCE Sec. 4.2.
ENABLE FREE FALL INTERRUPTS
TIME DELAY 1.7 SEC
Y1 GIMBAL MOTOR START
Y1 GIMBAL MOTOR ON
P1 GIMBAL MOTOR START
Ts
Ts
Ts
Ts
Ts+1
Ts+1.5
Ts+1.5
SCS MODE
G&N MONITOR MODE
G&N MODE
FINE ALIGN MODE

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
T_o-619.95		T_s+1.7		FIRE ADAPTER CSM SEPARATION SQUIB'S	ADAPTER CSM SEPARATION			
		T_s+1.7					CHECK ABORT FLAG	
		T_s+1.7					N: CHANGE FREE FALL CALC. ALTITUDE FROM 280,000 FT TO 400,000 FT Y: SEE "ABORT WITHOUT TUMBLING" SEQUENCE Sec. 4.2	
		T_s+1.7					CALL "SPS ENGINE ON" IN 11 SEC	
		T_s+1.7					START V_g, THRUST DIRECTION AND MANEUVER CALCULATION	
		T_s+2.0			P_1 GIMBAL MOTOR ON			
		T_s+2.0			Y_2 GIMBAL MOTOR START			
		T_s+2.5			Y_2 GIMBAL MOTOR ON			
		T_s+2.5			P_2 GIMBAL MOTOR START			
		T_s+2.5		SCS RCS ENABLE ON	SCS RCS ENABLE ON			
					ROLL CHANNEL UNDER CONTROL OF ROLL RATE GYRO: ATTITUDE ERROR AT OR NEAR NULL DUE TO FINE ALIGN MODE IN G&N PITCH AND YAW CHANNEL INHIBITED BY DIRECT ULLAGE			

SCS MODE ← G&N MONITOR MODE →

G&N MODE ← FINE ALIGN MODE →

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		T_s +2.5				ARM G&N CONTROL RELAYS: (1) G&N ATT. CONT. MODE CMND. (2) G&N ΔV MODE CMND. (3) G&N ENTRY MODE CMND. (4) +X TRANS ON/OFF		
		T_s +2.5			SET G&N ATT. CONT. MODE	COMMAND G&N ATT. CONT. MODE (COMMANDED BY AGC AT T_s: ENABLED BY MCP ARMING)		
		T_s +2.5			+X TRANS ON. INHIBITED IF NO RCS ENABLE (MESC ORIGINATED AT T_s +2.5) AND THEN ALSO INHIBITED BY DIRECT ULLAGE (MESC TERMINATED WHEN SIVB/CSM SEP CMND. IS TERMINATED BY THE MCP.)	COMMAND +X TRANS ON (COMMANDED BY AGC AT T_s: ENABLED BY MCP ARMING)		
		T_s +2.5			SPS ENGINE HOLD DISABLED	DISABLE SPS ENGINE HOLD		
		T_s +2.5			ARM SPS SOLONOIDS	ARM SPS SOLONOIDS		
		T_s +2.5			SPS GIMBALS GO TO TRIM POSITION #1	SELECT GIMBAL MOTOR TRIM POSITION #1		
		T_s +2.5			PRETHRUST VALVES OPENED	OPEN SPS PRETHRUST VALVES		

SCS MODE ← G&N MONITOR MODE → G&N ATT. CONT. MODE

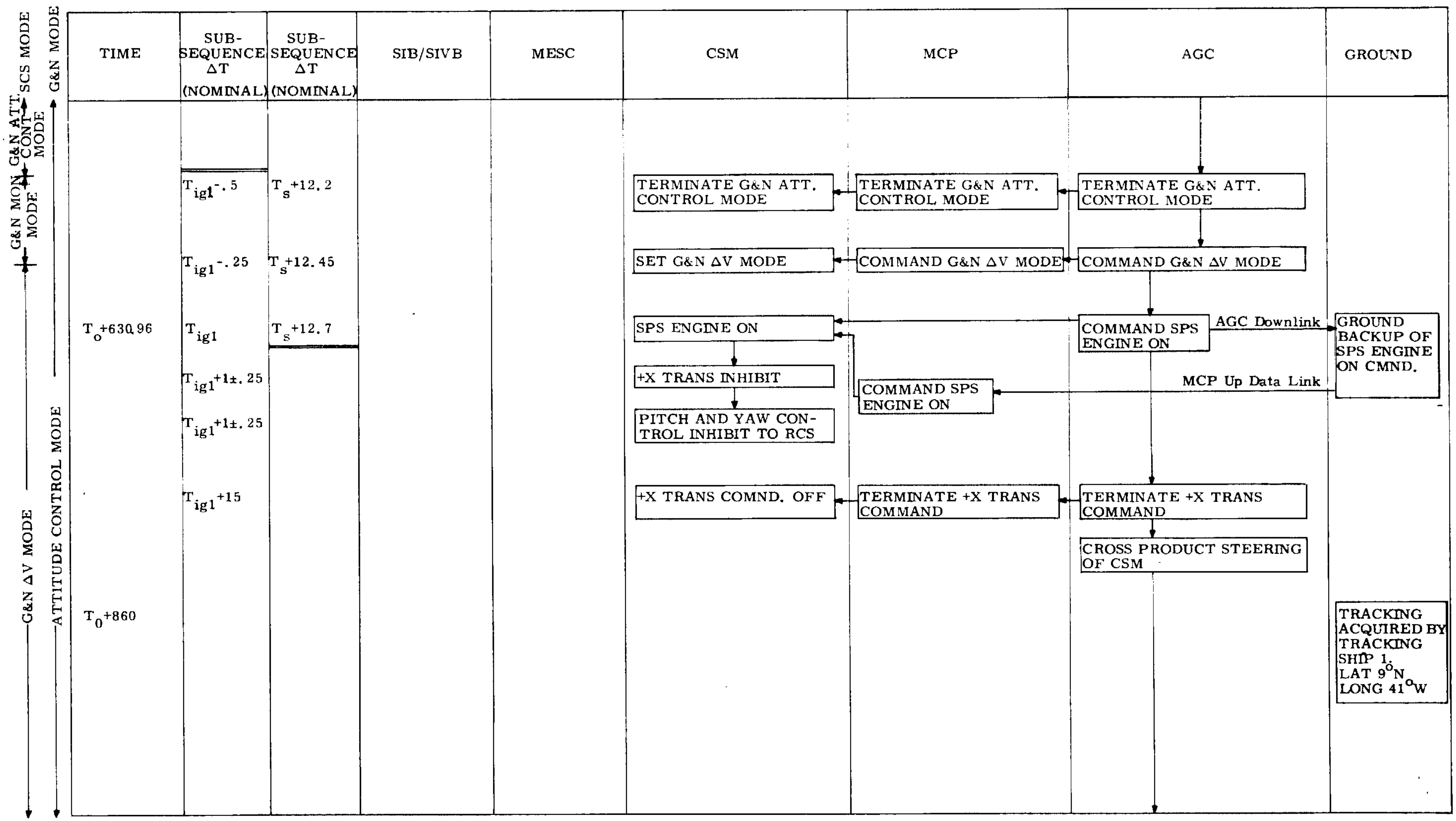
G&N MODE ← FINE ALIGN MODE →

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB SIVB	MESC	CSM	MCP	AGC	GROUND
		$T_s+2.5$			+X TRANS LOGIC INTER-LOCK TO TVC LOGIC	+X TRANS COMND. (TO TVC LOGIC ONLY)		
		$T_s+3.0$		SIVB/CSM SEPARATION COMMAND TERMINATED	DEENERGIZE VIA TRANSLATION HAND CON-TROLLER (ABORT POSITION)	TERMINATE SIVB CSM SEPARATION COMMAND		
		$T_s+3.0$		DIRECT ULLAGE COMMAND TERMINATED	DIRECT ULLAGE OFF			
		$T_s+3.0$			+X TRANS ON (INHIBIT RELEASED). PITCH AND YAW ATTITUDE CON-TROL ON (INHIBIT RE-LEASED). PITCH AND YAW UNDER CONTROL OF RATE GYROS. ATTITUDE ERRORS AT OR NEAR NULL DUE TO FINE ALIGN MODE IN G&N.			
	$T_{co-s}+1.3$	$T_s+3.0$			P2 GIMBAL MOTOR ON			
$T_o+624.09$*	$T_s+3.7\ {}^{+1.7}_{-0.3}$						COMMAND G&N SYSTEM TO ATTITUDE CONTROL MODE	
$T_o+624.96$*							START CDU DRIVE PITCH/YAW MANEUVER	
$T_o+626.96$*							STOP CDU TORQUING, AGC ASSUMES VEHICLE IS AT CORRECT ORIENTATION FOR 1ST SPS BURN	

G&N MODE — FINE ALIGN MODE — ATT. CONT. MODE

SCS MODE — G&N ATT. CONT. MODE

* See para. 4.3.



TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
$T_{ig1}-.5$
$T_s+12.2$
$T_{ig1}-.25$
$T_s+12.45$
$T_o+630.96$
T_{ig1}
$T_s+12.7$
$T_{ig1}+1\pm.25$
$T_{ig1}+1\pm.25$
$T_{ig1}+15$
T_0+860
TERMINATE G&N ATT. CONTROL MODE
TERMINATE G&N ATT. CONTROL MODE
TERMINATE G&N ATT. CONTROL MODE
SET G&N ΔV MODE
COMMAND G&N ΔV MODE
COMMAND G&N ΔV MODE
SPS ENGINE ON
COMMAND SPS ENGINE ON
AGC Downlink
GROUND BACKUP OF SPS ENGINE ON CMND.
MCP Up Data Link
COMMAND SPS ENGINE ON
+X TRANS INHIBIT
PITCH AND YAW CONTROL INHIBIT TO RCS
+X TRANS COMND. OFF
TERMINATE +X TRANS COMMAND
TERMINATE +X TRANS COMMAND
CROSS PRODUCT STEERING OF CSM
TRACKING ACQUIRED BY TRACKING SHIP 1. LAT 9°N LONG 41°W
G&N MON MODE
G&N ATT. CONT MODE
SCS MODE
G&N ΔV MODE
G&N MODE
ATTITUDE CONTROL MODE

SCS MODE: G&N ΔV MODE — G&N MON MODE — G&N ATT. CONT. MODE

G&N MODE: ATTITUDE CONT. MODE

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
$T_o+864.81$	$T_{ig1}+234.19$	T_{col}			SPS ENGINE OFF	COMMAND SPS ENGINE OFF	COMMAND SPS ENGINE OFF AGC Downlink MCP Up Data Link	GROUND BACKUP OF SPS ENGINE OFF CMND.
		$T_{col}+1\pm.25$			PITCH AND YAW CONTROL INHIBIT RELEASED TO RCS.			
		$T_{col}+7$				TIME DELAY - 3 SEC	COMMAND SPS MOTOR POWER OFF	
		$T_{col}+10$			SPS GIMBAL MOTOR POWER OFF	COMMAND SPS GIMBAL MOTOR POWER OFF		
		$T_{col}+10$			PRETHRUST VALVES CLOSED	CLOSE SPS PRETHRUST VALVES		
		$T_{col}+10$				STOP FQ TAPE RECORDER		
		$T_{col}+10$			SPS GIMBALS COMMANDED TO TRIM POSITION #2. RESPONSE INHIBITED WITHOUT GIMBAL MOTOR POWER	SELECT GIMBAL MTR. TRIM POSITION #2		
		$T_{col}+10.50$			TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	
		$T_{col}+10.75$			SET G&N ATT. CONT. MODE	COMMAND G&N ATT. CONT. MODE	COMMAND G&N ATT. CONT. MODE	

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
					COAST			
							COMPUTE ATTITUDE MANEUVER NECESSARY TO POINT +X AXIS TOWARD EARTH'S CTR.	
$T_s+876.42^*$							START PITCH/YAW MANEUVER	
$T_s+912.42^*$							PITCH YAW MANEUVER COMPLETED. START LOCAL VERTICAL PHASE.	
T_o+960								TRACKING LOST BY ANTIGUA (B. W. I.)
		$T_{co1}+300$			START FDAI ALIGN	START FDAI ALIGN	COMMAND START FDAI ALIGN	
		$T_{co1}+310$			STOP FDAI ALIGN	STOP FDAI ALIGN	STOP FDAI ALIGN	
T_o+1340								TRACKING LOST BY TRACKING SHIP 1 60 sec without ground coverage

SCS MODE ← G&N ATT. CONT. MODE →

G&N MODE ← ATT. CONT. MODE →

* See Para. 4.3.

SCS MODE — G&N ATT. CONT. MODE

G&N MODE — ATT. CONT. MODE

TIME	SUB SEQUENCE ΔT (NOMINAL)	SUB SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
T_o+1400								TRACKING ACQUIRED BY ASCENSION IS LAT. 07°57' 05"S LONG. 14° 24'45"W
T_o+1880								TRACKING LOST BY ASCENSION ISLAND 140 sec without ground coverage
T_o+2320								TRACKING ACQUIRED BY PRETORIA S.A. LAT. 25°56' 14'S LONG. 28°22' 64"W
T_o+2800								TRACKING LOST BY PRETORIA 960 sec without ground coverage

SCS MODE: G&N ATT. CONT. MODE

G&N MODE: ATT. CONT. MODE

2ND SPS BURN

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		T_{co1}+203717					STOP LOCAL VERTICAL MODE	
							CALCULATE : (A) VEHICLE POSITION AND VELOCITY FOR 2ND BURN IGNITION (B) VEHICLE ATTITUDE REQUIRED FOR 2ND BURN IGNITION	
T_o+2946.97*							START PITCH/YAW MANEUVER	
T_o+2953.47*							COMPLETE PITCH/YAW MANEUVER	
T_o+3760								TRACKING ACQ. BY CARNARVON AUST. LAT. 24°52' 00"S LONG. 113° 38'00"E
Completed at least by T_o+3978	Completed at least by T_{ig2}-50						R. V. T. UPDATE (AGC Uplink / AGC Downlink)	TRANSMIT R. V. T. AGC UPDATE
							BASED ON ELAPSED TIME FROM 1ST SPS BURN CUTOFF AGC STARTS 2ND SPS BURN SEQUENCE	
T_o+3998.48	T_{ig2}-30	T_{co1}+3133.68			+X TRANS. ON	COMMAND +X TRANS.	COMMAND +X TRANS.	

*See para. 4.3.

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
	$T_{ig2}-4$				GIMBAL MOTORS START SEQUENCE START	START GIMBAL MOTOR START SEQUENCE (3 SEC DETAILED FOR SIVB/CSM SEPARATION ONLY)	COMMAND GIMBAL MOTOR ON	
	$T_{ig2}-4$					START FQ TAPE RECORDER		
	$T_{ig2}-2.5$				SPS YAW GIMBAL TO TRIM POSITION #2			
	$T_{ig2}-2$				SPS PITCH GIMBAL TO TRIM POSITION #2			
	$T_{ig2}-1$				GIMBAL MOTORS ON			
	$T_{ig2}-1$				PRETHRUST VALVES OPENED	OPEN SPS PRETHRUST VALVES		
	$T_{ig2}-.5$				TERMINATE G&N ATT. CONT. MODE	TERMINATE G&N ATT. CONT. MODE	TERMINATE G&N ATT. CONT. MODE	
	$T_{ig2}-.25$				SET G&N ΔV MODE	CMND. G&N ΔV MODE	COMMAND G&N ΔV MODE	
$T_o+4028.48$	T_{ig2}	$T_{co1}+3163.68$			SPS ENGINE ON		COMMAND SPS ENGINE ON AGC Downlink	GND BACK-UP OF SPS ENGINE ON COMMAND
						COMMAND SPS ENGINE ON	MCP Up Data Link	
	$T_{ig2}+1\pm.25$				+X TRANS INHIBIT			
	$T_{ig2}+1\pm.25$				PITCH AND YAW CONTROL INHIBIT TO RCS			
							CROSS PRODUCT STEERING OF CSM	
							HOLD CDU'S (STOP TORQUING) VEHICLE REMAINS AT THIS ATTITUDE UNTIL COMPLETION OF 4TH BURN	

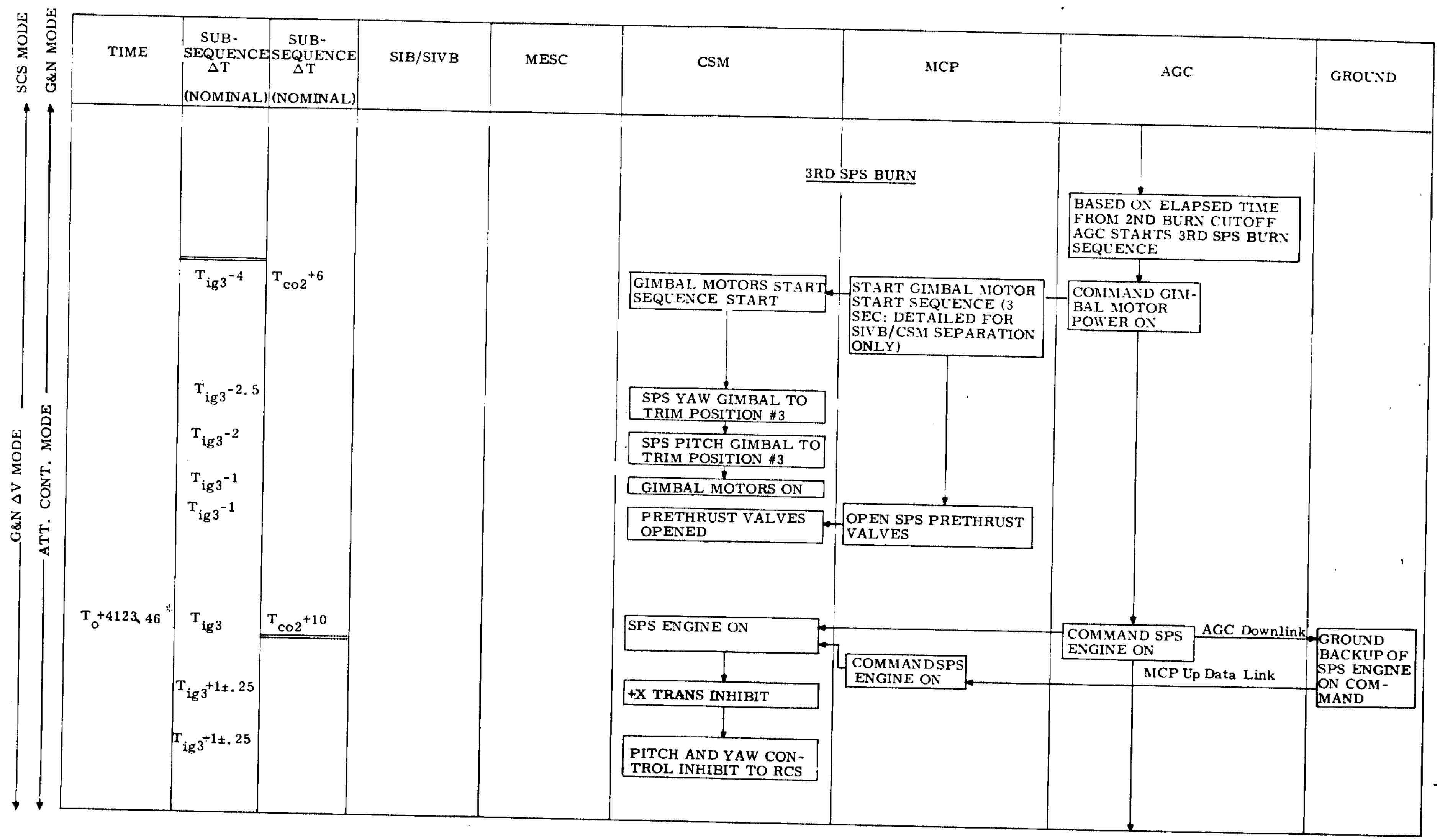
G&N ΔV MODE — G&N MON. MODE — G&N ATT. CONT. MODE — SCS MODE

ATT. CONT. MODE — G&N MODE

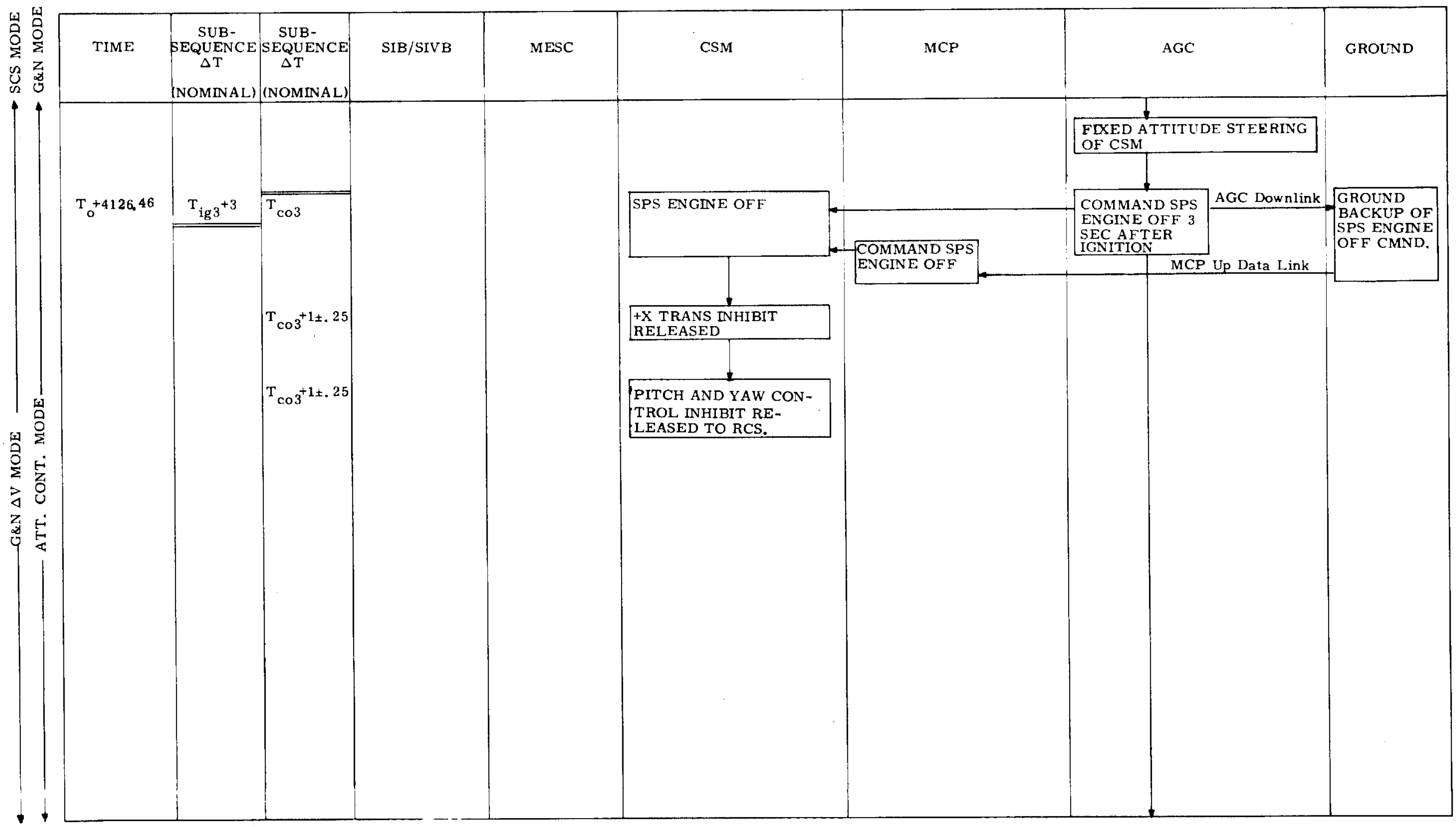
TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
$T_o+4113.46$	$T_{ig2}+86$	T_{co2}			SPS ENGINE OFF	COMMAND SPS ENGINE OFF	COMMAND SPS ENGINE OFF AGC Downlink MCP Up Data Link	GROUND BACKUP OF SPS ENGINE OFF COMMAND
		$T_{co2}+.75$					SUBTRACT THE DIFFERENCE BETWEEN THE #2 AND #3 PITCH AND YAW GIMBAL MOTOR TRIM ANGLES FROM CDU'S TO ENSURE CONSTANT CSM ATTITUDE	
		$T_{co2}+1\pm.25$			RELEASE +X TRANS INHIBIT			
		$T_{co2}+1\pm.25$			PITCH AND YAW CONTROL INHIBIT RELEASED TO RCS.			
		$T_{co2}+2$				TIME DELAY - 3 SEC	COMMAND GIMBAL MOTOR POWER OFF	
		$T_{co2}+5$			GIMBAL MOTOR POWER OFF	COMMAND GIMBAL MOTOR PWR. OFF		
		$T_{co2}+5$			SPS GIMBALS COMMANDED TO TRIM POSITION #3. RESPONSE INHIBITED WITHOUT GIMBAL MOTOR PWR.	SELECT GIMBAL TRIM POSITION #3.		
		$T_{co2}+5$			PRETHRUST VALVES CLOSED	CLOSE SPS PRETHRUST VALVES		

G&N MODE ← → ATT. CONT. MODE

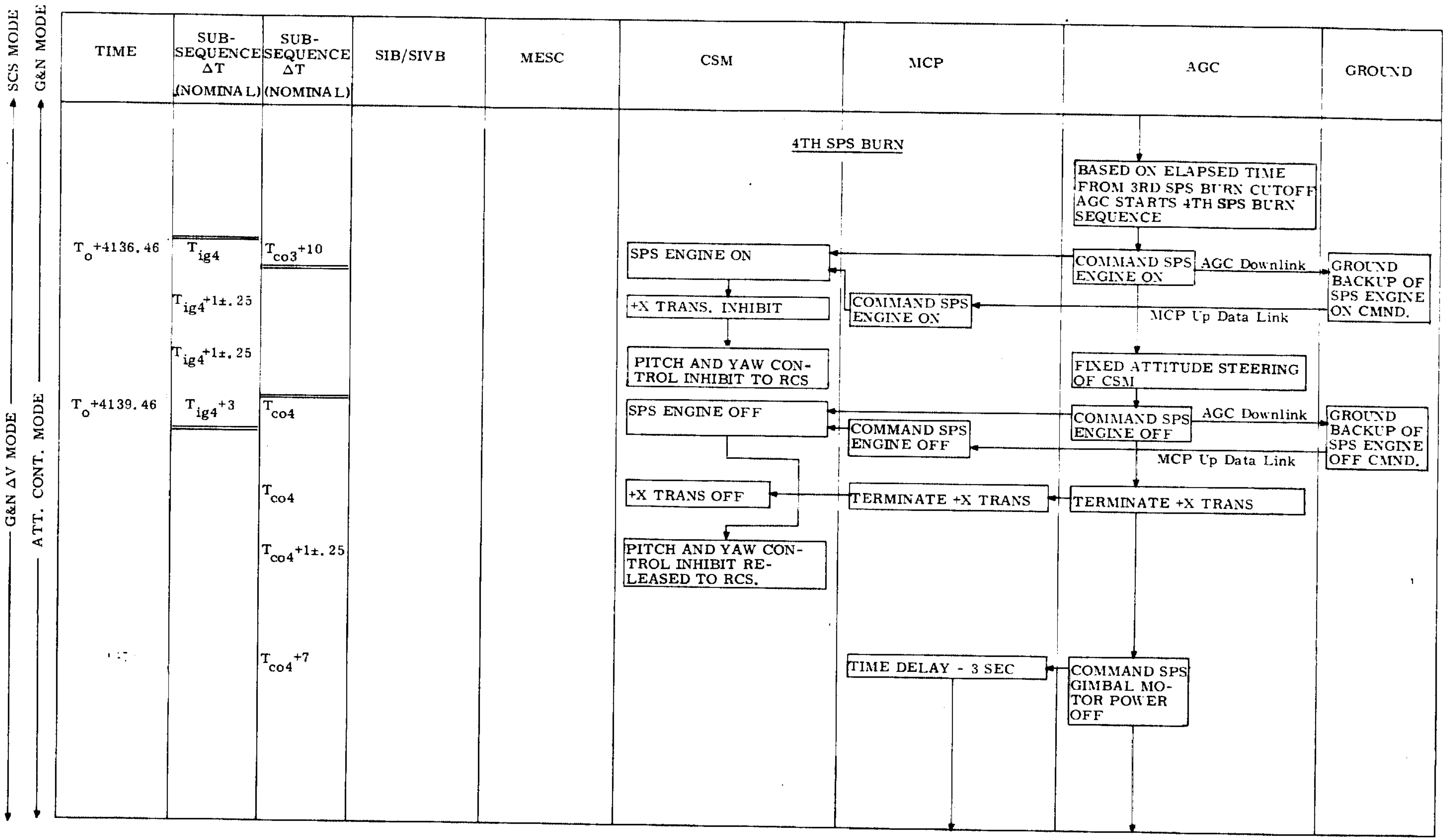
SCS MODE ← → G&N ΔV MODE



SCS MODE
G&N MODE
G&N ΔV MODE
ATT. CONT. MODE
TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
3RD SPS BURN
BASED ON ELAPSED TIME FROM 2ND BURN CUTOFF AGC STARTS 3RD SPS BURN SEQUENCE
COMMAND GIMBAL MOTOR POWER ON
START GIMBAL MOTOR START SEQUENCE (3 SEC: DETAILED FOR SIVB/CSM SEPARATION ONLY)
GIMBAL MOTORS START SEQUENCE START
SPS YAW GIMBAL TO TRIM POSITION #3
SPS PITCH GIMBAL TO TRIM POSITION #3
GIMBAL MOTORS ON
PRETHRUST VALVES OPENED
OPEN SPS PRETHRUST VALVES
SPS ENGINE ON
COMMAND SPS ENGINE ON
COMMANDSPS ENGINE ON
AGC Downlink
MCP Up Data Link
GROUND BACKUP OF SPS ENGINE ON COMMAND
+X TRANS INHIBIT
PITCH AND YAW CONTROL INHIBIT TO RCS
$T_{ig3}-4$
$T_{co2}+6$
$T_{ig3}-2.5$
$T_{ig3}-2$
$T_{ig3}-1$
$T_{ig3}-1$
$T_o+4123.46$
T_{ig3}
$T_{co2}+10$
$T_{ig3}+1\pm.25$
$T_{ig3}+1\pm.25$



TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
FIXED ATTITUDE STEERING OF CSM
COMMAND SPS ENGINE OFF 3 SEC AFTER IGNITION
AGC Downlink
GROUND BACKUP OF SPS ENGINE OFF CMND.
MCP Up Data Link
COMMAND SPS ENGINE OFF
SPS ENGINE OFF
+X TRANS INHIBIT RELEASED
PITCH AND YAW CONTROL INHIBIT RELEASED TO RCS.
T_o+4126.46
T_{ig3}+3
T_{co3}
T_{co3}+1±.25
T_{co3}+1±.25
SCS MODE
G&N MODE
G&N ΔV MODE
ATT. CONT. MODE



TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
SIB/SIVB
MESC
CSM
MCP
AGC
GROUND
4TH SPS BURN
BASED ON ELAPSED TIME FROM 3RD SPS BURN CUTOFF AGC STARTS 4TH SPS BURN SEQUENCE
T_o+4136.46
T_{ig4}
T_{co3}+10
SPS ENGINE ON
COMMAND SPS ENGINE ON
AGC Downlink
GROUND BACKUP OF SPS ENGINE ON CMND.
T_{ig4}+1±.25
+X TRANS. INHIBIT
COMMAND SPS ENGINE ON
MCP Up Data Link
T_{ig4}+1±.25
PITCH AND YAW CONTROL INHIBIT TO RCS
FIXED ATTITUDE STEERING OF CSM
T_o+4139.46
T_{ig4}+3
T_{co4}
SPS ENGINE OFF
COMMAND SPS ENGINE OFF
COMMAND SPS ENGINE OFF
AGC Downlink
GROUND BACKUP OF SPS ENGINE OFF CMND.
MCP Up Data Link
T_{co4}
+X TRANS OFF
TERMINATE +X TRANS
TERMINATE +X TRANS
T_{co4}+1±.25
PITCH AND YAW CONTROL INHIBIT RELEASED TO RCS.
T_{co4}+7
TIME DELAY - 3 SEC
COMMAND SPS GIMBAL MOTOR POWER OFF
SCS MODE
G&N ΔV MODE
G&N MODE
ATT. CONT. MODE

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
		$T_{co4}+10$			SPS GIMBAL MOTOR POWER OFF	COMMAND SPS GIMBAL MOTOR POWER OFF		
		$T_{co4}+10$			PRETHRUST VALVES CLOSED	CLOSE SPS PRETHRUST VALVES		
		$T_{co4}+10.50$			TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	TERMINATE G&N ΔV MODE	
		$T_{co4}+10.75$			SET G&N ATT. CONT. MODE	COMMAND G&N ATT. CONT. MODE	COMMAND G&N ATT. CONT. MODE	
							HOLD ATTITUDE UNTIL FREE FALL INTERRUPT	
T_o+4160								TRACKING ACQUIRED BY TRACKING SHIP #2 LAT. 7.5°S LONG. 132.0°E
T_o+4160								TRACKING LOST BY CARNARVON AUST

SCS MODE: G&N ΔV MODE — G&N MON MODE — G&N ATT. CONT. MODE

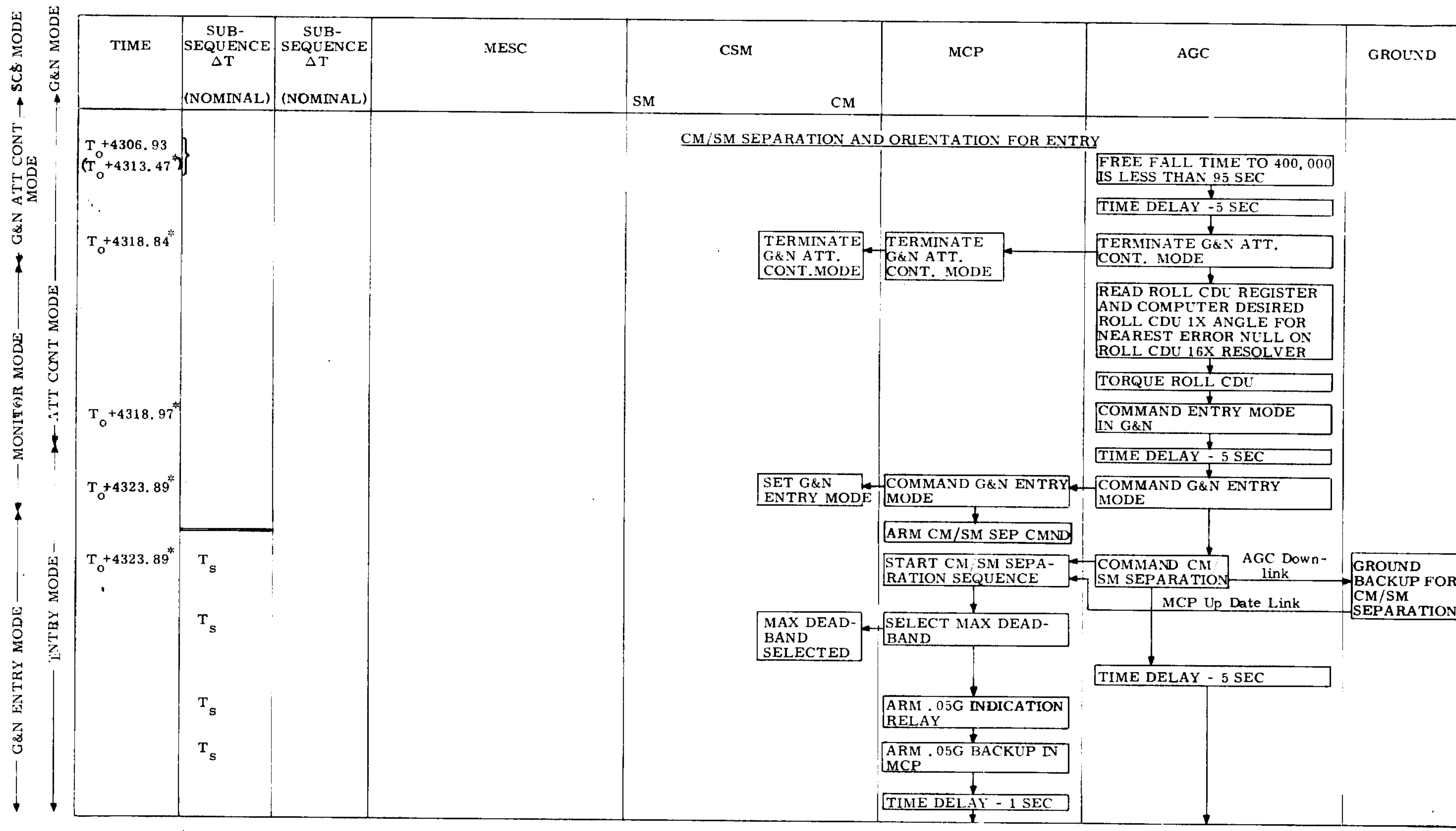
G&N MODE: ATT. CONT. MODE

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	SIB/SIVB	MESC	CSM	MCP	AGC	GROUND
					CM/SM SEPARATION ORIENTATION			
T_o+4241.93							FREE FALL TIME TO 400,000 FT. IS LESS THAN 160 SEC	
							→ READ TOTAL VEHICLE ATTITUDE AND CALCULATE ATTITUDE MANEUVER	
T_o+4248.45*							→ START VEHICLE REORIENTATION TO CM/SM SEPARATION ATTITUDE: START PITCH/YAW MANEUVER	
T_o+4270.95*							→ COMPLETE PITCH/YAW MANEUVER	
							→ STANDBY FOR CM SM SEPARATION COMMAND TO BE KEYED ON FREE FALL TIME TO 400,000' CALCULATION	

SCS MODE ← G&N ATT. CONT. MODE →

G&N CODE ← ATT. CONT. MODE →

*See para. 4.3.



TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
MESC
CSM
SM
CM
MCP
AGC
GROUND
CM/SM SEPARATION AND ORIENTATION FOR ENTRY
T₀+4306.93
(T₀+4313.47*)
T₀+4318.84*
T₀+4318.97*
T₀+4323.89*
T₀+4323.89*
Ts
Ts
Ts
Ts
FREE FALL TIME TO 400,000 IS LESS THAN 95 SEC
TIME DELAY -5 SEC
TERMINATE G&N ATT. CONT. MODE
READ ROLL CDU REGISTER AND COMPUTER DESIRED ROLL CDU 1X ANGLE FOR NEAREST ERROR NULL ON ROLL CDU 16X RESOLVER
TORQUE ROLL CDU
COMMAND ENTRY MODE IN G&N
TIME DELAY - 5 SEC
COMMAND G&N ENTRY MODE
COMMAND CM/SM SEPARATION
AGC Down-link
MCP Up Date Link
TIME DELAY - 5 SEC
GROUND BACKUP FOR CM/SM SEPARATION
TERMINATE G&N ATT. CONT. MODE
COMMAND G&N ENTRY MODE
ARM CM/SM SEP CMND
START CM/SM SEPARATION SEQUENCE
SELECT MAX DEAD-BAND
ARM .05G INDICATION RELAY
ARM .05G BACKUP IN MCP
TIME DELAY - 1 SEC
TERMINATE G&N ATT. CONT.MODE
SET G&N ENTRY MODE
MAX DEAD-BAND SELECTED
G&N MODE
SCS MODE
G&N ATT CONT MODE
ATT CONT MODE
MONITOR MODE
ENTRY MODE
G&N ENTRY MODE

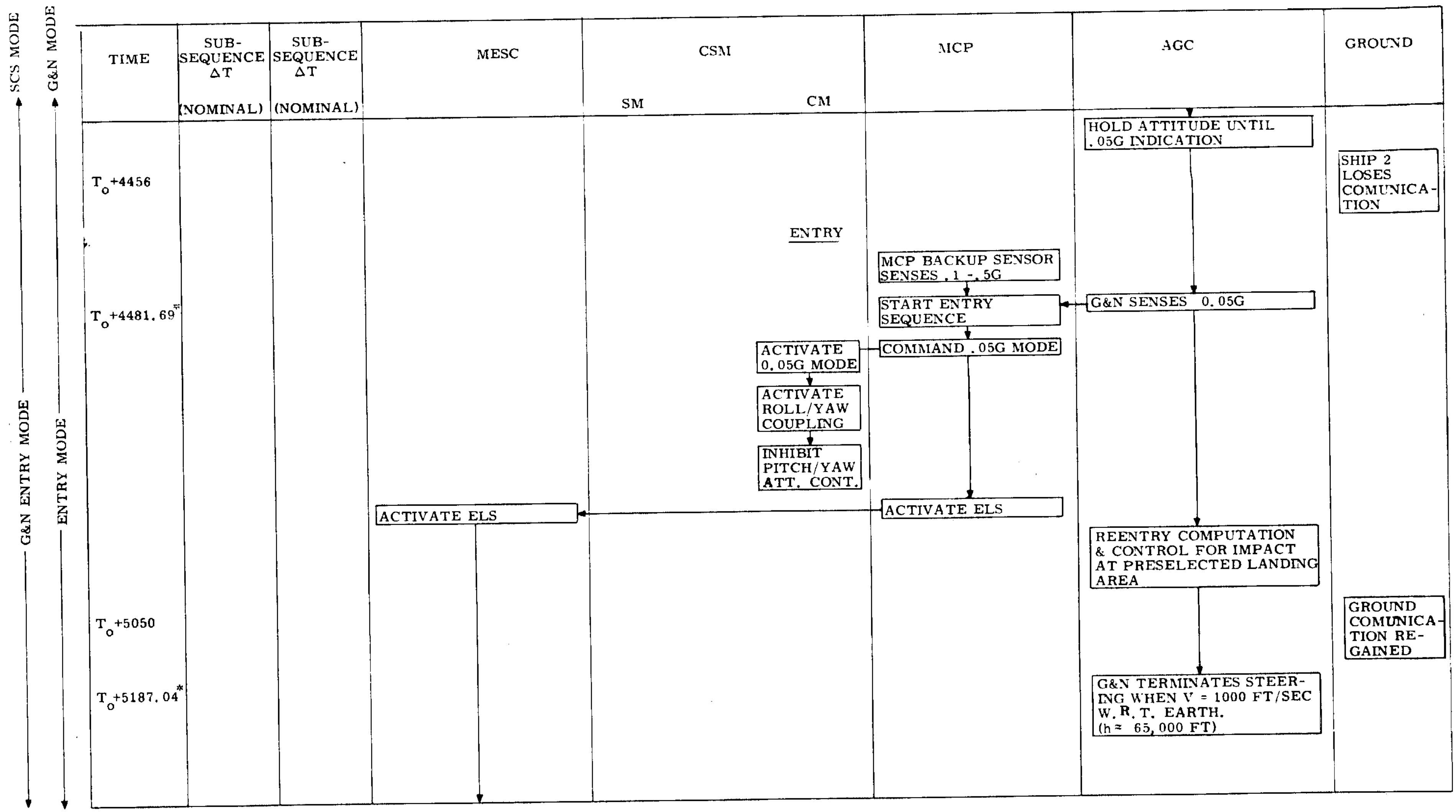
*See para. 4.3.

TIME	SUB-SEQUENCE ΔT (NOMINAL	SUB-SEQUENCE ΔT (NOMINAL)	MESC	CSM SM	CSM CM	MCP	AGC	GROUND
		$T_s+1.0$	START CM/SM SEPARATION SEQUENCE			COMMAND CM/SM SEPARATION		
		$T_s+1.0$	CM/SM UMBILICAL DEADFACE					
		$T_s+1.0$	PRESSURIZE CM RCS					
		$T_s+1.0$	TRANSFER S/C ATTITUDE CONTROL FROM SM TO CM REACTION JETS					
		$T_s+1.0$	START SM JETTISON SEQUENCE	START SM JETTISON SEQUENCE				
		$T_s+1.0$		FIRE -X TRANSLATION SM				
		$T_s+1.1$	FIRE CM/SM TENSION TIES					
		T_s+3		ENERGIZE +ROLL SM RCS				
							READ TOTAL VEHICLE ATTITUDE AND CALCULATE ATTITUDE MANUEVER	
$T_o+4330.00$*		T_s+6					START VEHICLE REORIENTATION TO PRE-ENTRY ATTITUDE: START PITCH/YAW MANEUVER	
		$T_s+8.5$		TERMINATE +ROLL				
				-X TRANS CONTINUES TO SM RCS FUEL DEPLETION				
$T_o+4369.00$*							COMPLETE PITCH/YAW MANEUVER	

SCS MODE ◄ — G&N ENTRY MODE ►

G&N MODE ◄ — ENTRY MODE ►

*See para. 4.3.


SCS MODE
G&N ENTRY MODE
G&N MODE
ENTRY MODE
TIME
SUB-SEQUENCE ΔT (NOMINAL)
SUB-SEQUENCE ΔT (NOMINAL)
MESC
CSM
SM
CM
MCP
AGC
GROUND
T$_o$+4456
T$_o$+4481.69*
T$_o$+5050
T$_o$+5187.04*
HOLD ATTITUDE UNTIL .05G INDICATION
SHIP 2 LOSES COMUNICATION
ENTRY
MCP BACKUP SENSOR SENSES .1 - .5G
START ENTRY SEQUENCE
G&N SENSES 0.05G
ACTIVATE 0.05G MODE
COMMAND .05G MODE
ACTIVATE ROLL/YAW COUPLING
INHIBIT PITCH/YAW ATT. CONT.
ACTIVATE ELS
ACTIVATE ELS
REENTRY COMPUTATION & CONTROL FOR IMPACT AT PRESELECTED LANDING AREA
GROUND COMUNICATION REGAINED
G&N TERMINATES STEERING WHEN V = 1000 FT/SEC W.R.T. EARTH. (h ≈ 65,000 FT)

*See para. 4.3.

SCS MODE

G&N MODE

TIME	SUB-SEQUENCE ΔT (NOMINAL)	SUB-SEQUENCE ΔT (NOMINAL)	MESC	CSM SM	CSM CM	MCP	AGC	GROUND
			ELS 25K BARO SWITCH ACTIVATED					
			SCS RCS ENABLE OFF		SCS RCS ENABLE OFF		G&N LOOSES ABILITY TO CONTROL ATTITUDE OF CM	
			CONTINUE POST ENTRY AND RECOVERY SEQUENCE					
T_o+5648						IMPACT SYSTEM SENSES IMPACT		
T_o+5649						POWER OFF ALL CM SYSTEM EXCEPT RECOVERY SYSTEMS	POWER OFF G&N	

5. GUIDANCE AND CONTROL EQUATIONS

5.1 Powered Flight Guidance Scheme

The guidance scheme for Mission 202 is the same as that planned for all Apollo CSM powered flights. It is based on the possibility of an analytical description of a required velocity ($\underline{v}_r$) which is defined as the velocity required at the present position $\underline{r}$, in order to achieve the stated objective of a particular powered flight maneuver.

If $\underline{v}$ is the present velocity, then the velocity to be gained ($\underline{v}_g$) is given by

$$\underline{v}_g = \underline{v}_r - \underline{v} \tag{1}$$

Differentiation of both sides yields

$$\dot{\underline{v}}_g = \dot{\underline{v}}_r - \dot{\underline{v}} \tag{2}$$

$$= \dot{\underline{v}}_r - \underline{g} - \underline{a}_T \tag{3}$$

$$= \underline{b} - \underline{a}_T \tag{4}$$

where

$$\underline{b} = \dot{\underline{v}}_r - \underline{g} \tag{5}$$

and $\underline{g}$ is the gravitational acceleration.

The steering command is developed by formulating a desired thrust acceleration ($\underline{a}_{T_D}$) as that which satisfies the equation

$$\underline{a}_{T_D} * \underline{v}_g = c\underline{b} * \underline{v}_g \tag{6}$$

where c is a constant scalar.

*Indicates vector cross product

Hence a measure of the error between $\underline{a}_{T_D}$ and the actual acceleration $\underline{a}_T$ is given by

$$\underline{\omega}_c = \frac{\underline{v}_g * \dot{\underline{m}}}{|\underline{v}_g| \; |\dot{\underline{m}}|} \tag{7}$$

where

$$\dot{\underline{m}} = c\underline{b} - \underline{a}_T \tag{8}$$

It can be verified that $\underline{\omega}_c$ is also the axis about which the thrust vector should be rotated to null the error. Hence $\underline{\omega}_c$ is used in forming the steering command.

Once a required velocity $\underline{v}_r$ is defined satisfactorily, the procedure for the generation of the error vector $\underline{\omega}_c$ is the same for all phases of powered flight. The equations for the required velocity for the various phases are described in the succeeding pages. Descriptions of the initial alignment procedure, ignition and cutoff logic and implementation in AGC are also included.

5.2 Nominal Mission

5.2.1 Required Velocity

The required velocity for the first and second burns of the nominal mission is defined as that velocity which will put the vehicle in an elliptical trajectory of predefined parameters (semi major axis a, and eccentricity e). The values used are

	First Burn	Second Burn
a	2.2491076×10^7 feet	2.8290953×10^7 feet
e	0.10988556	0.25341222

These numbers correspond to the trajectory described in Section 6. The value of c in Eq. (6) is 0.5.

The required velocity can be written as

$$\underline{v}_r = \underline{i}_r \, v_{rad} + i_H \, v_H \tag{9}$$

where

$$v_{rad} = \pm \left[\frac{\mu}{p} \left[e^2 - (\frac{p}{r} - 1)^2\right]\right]^{1/2} \tag{10}$$

$$v_H = +\left(\frac{\mu p}{r^2}\right)^{1/2} \tag{11}$$

$$p = a\,(1 - e^2) \tag{12}$$

$$\underline{i}_r = \frac{\underline{r}}{|\underline{r}|} \tag{13}$$

and

$$\underline{i}_H = \text{UNIT}\,(\underline{i}_N * \underline{i}_r) \tag{14}$$

The positive sign is used in Eq. (10) for the radial velocity during first burn and the negative sign is used during second burn.

5.2.2 Yaw Steering

Plane control during the nominal mission is achieved by specifying the normal ($\underline{i}_N$) to the required plane appearing in Eq. (14). The required trajectory plane is defined to be the plane containing the pressent position vector (r) and the landing site vector taken as point of drogue chute deployment at 24,000 ft ($\underline{r}_{LS}$; 17.25N, 170.00E) at the nominal time (5243.5 sec) of landing and is given by

$$\underline{i}_N = \text{UNIT}\,(\underline{r} * \underline{r}_{LS})\ \text{Sign}\ \left[(\underline{r} * \underline{r}_{LS}) \cdot \underline{i}_w\right] \tag{15}$$

where $\underline{i}_w$ is the earth's polar unit vector. At cutoff the vehicle velocity will be equal to $\underline{v}_r$, thereby ensuring the trajectory plane to be $\underline{i}_N$ according to Eqs. (9) and (14).

During the third and fourth burns, no computations are made for $\underline{v}_r$. The desired thrust direction is held fixed at the direction computed at the end of the second burn.

5.2.3 Engine Ignition

In the nominal mission the engine is always ignited after a fixed interval of time from a previous event. The first burn is initiated 12.7 seconds after receipt of SIV-B/CSM separation signal, the second burn 3163.67 seconds after first burn cutoff, the third burn 10 seconds after second burn cutoff and the fourth burn 10 seconds after third burn cutoff.

5.2.4 Engine Cutoff

During all the burns a time to cutoff (T_g) is continuously being estimated from the equation

$$T_g = k \underline{v}_g \cdot \underline{m} \ / \ |\underline{m}| \tag{16}$$

where k is a factor that is a first approximation to the thrust acceleration increase over 4 secs for SPS1, and 10 secs for SPS2.

$k = 0.995$ for SPS1

$k = 0.984$ for SPS2

The accuracy of T_g increases as $T_g \rightarrow 0$, because as $|\underline{v}_g| \rightarrow 0$, $|\underline{b}| \rightarrow 0$.

For the first burn, when T_g falls, for the first time, below the critical value of 4.0 seconds, the clock is set to turn off the engine T_g seconds later. For the second burn, when T_g falls, for the first time, below 10 secs, the clock is set to turn off the engine (T_g-6) secs later.

In the third and fourth burns the engine is turned off 3 seconds after ignition.

5.3 Aborts During Boost

The guidance equations for aborts during boost have been designed to meet the following constraints that have been imposed on the spacecraft attitude.

The visual horizon is to be kept on a hairline on the forward window during the entire powered flight and this line should be independent of the time at which abort is initiated.

The window geometry indicates that this requires the thrust direction to be between 4° and 36° to the line of sight to the visual horizon. Within this limitation, the larger the angle, the greater is the interval of time before nominal SIV-B cutoff during which the capability exists to reach a particular recovery area in the event of an abort. Hence a thrust angle of 35° to the line of sight to the horizon is used (See Fig. 5.1).

5.3.1 Required Velocity

The definition of a required velocity, in the usual sense, consistent with the direction of thrust pre-specified as above, is not possible. Hence, a pseudo required velocity is defined for aborts, which,

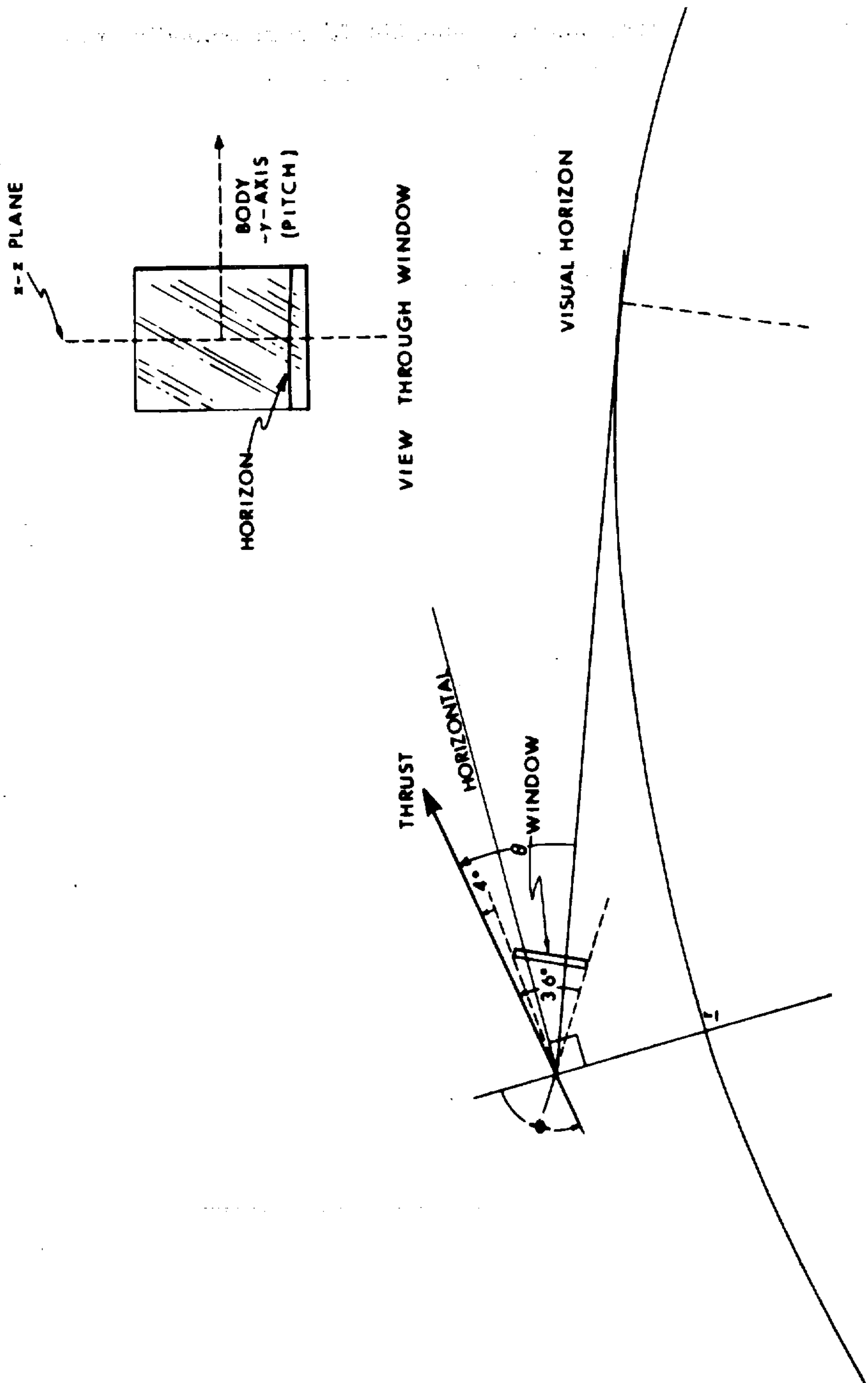


Fig. 5-1 Window Geometry

when incorporated into the general steering scheme, will satisfy not only the constraint on the thrust direction but also permit recovery from a specified landing area.

Let $\underline{r}_e$ be the entry position (400, 000 ft) corresponding to a free fall from the present position. Then we can write

$$x = \tan\left(\frac{\theta_f}{2}\right) \tag{17}$$

$$= \frac{r_e - r}{r_e \cot \gamma + r \cot \gamma_e} \tag{18}$$

and

$$\sin \theta_f = \frac{2x}{x^2 + 1} \tag{19}$$

$$\cos \theta_f = \frac{1 - x^2}{1 + x^2} \tag{20}$$

where

$$\cot \gamma = \frac{\underline{v} \cdot \underline{i}_r}{\underline{v} \cdot \underline{i}_H'} \tag{21}$$

$$\cot \gamma_e = r/p \left[e^2 - \left(\frac{p}{r_e} - 1\right)^2\right]^{1/2} \tag{22}$$

$$\underline{i}_H' = \underline{i}_p * \underline{i}_r \tag{23}$$

$$\underline{i}_p = \text{UNIT } (\underline{r} * \underline{v}) \tag{24}$$

θ_f is the free-fall central angle to the entry point,

r_e is the radius at 400, 000 ft altitude,

γ_e is the flight path angle w.r.t. the local vertical at entry

γ is the present flight path angle (w.r.t. vertical)

The entry-point is given by

$$\underline{r}_e = r_e (\underline{i}_r \cos \theta_f + \underline{i}_{H'} \sin \theta_f) \tag{25}$$

Now let $\underline{r}_T$ be the desired landing site (target vector) at the nominal time. The target vector for aborts is the inertial position of 4.00°N and 329°E longitude at 1420 seconds from lift-off. This choice corresponds to minimum plane change for aborts at 609.95 seconds from the nominal boost trajectory. The normal ($\underline{1}_N$) to the desired plane is defined in section 5.3.2.

The desired entry point ($\underline{r}_{ed}$) is a function of the entry velocity and flight path angle. This vector is computed during each computational repetition as a function of the expected entry velocity and the inertial location of the nominal landing site.

If the engine were to be cut-off at the present time, the velocity at entry (v_e) will be (from the vis-viva integral)

$$v_e = (v^2 + 2\,\mu\,(\frac{1}{r_e} - \frac{1}{r}))^{1/2} \tag{25a}$$

Based on this velocity v_e an anticipated entry range (ϕ_e) is computed from an empirical formula

$$\phi_e = \frac{6076.15}{R_e}\,(.1875\,v_e - 3712.5) \qquad (25b)^{\#}$$

if $v_e \geqq 21400$ ft/sec, and

$$\phi_e = \frac{6076.15}{R_e}\,(411) \tag{25c}$$

if $v_e < 21400$ ft/sec.

The desired entry vector ($\underline{r}_{ed}$) is computed as

$$\underline{r}_{ed} = r_e\,(\underline{1}_{r_{LS}}\ \mathrm{Cos}\,\phi_e - \mathrm{UNIT}\ (\underline{1}_N * \underline{1}_{r_{LS}})\ \sin\phi_e) \tag{25d}$$

At cut-off, $\underline{r}_{ed} = \underline{r}_e$ and the actual entry velocity is v_e, satisfying the entry range equation.

The error d can be written as

$$d = \left|\underline{r}_{ed} - \underline{r}_e\right| \tag{26}$$

#It should be noted that Eq. (25b) does not take into account the entry flight path angle. The co-efficients are pre-computed on the basis of the nominal trajectory and hence the flight path angle is implied in Eq. (25b).

The rate of change of this error is computed by differencing $\underline{r}_e$ as

$$\dot{d} = \frac{\Delta d}{\Delta t} \tag{27}$$

$$\cong \left| \underline{r}_{e_{n-1}} - \underline{r}_{e_{n-1}} \right| / \Delta t \tag{28}$$

where the subscript n denotes the nth computational repetition.

Observing that $d/\dot{d}$ is a measure of the time to cutoff (T_g), let the magnitude of $\underline{v}_g$ be defined as

$$\left| \underline{v}_g \right| = \frac{d}{\dot{d}} \left| \underline{a}_T \right| \tag{29}$$

or

$$\left| \underline{v}_g \right| = \frac{d}{\Delta d} \left| \Delta V \right| \tag{30}$$

where $\underline{\Delta v}$ is the velocity increment measured with the accelerometers in the interval Δt. This formulation of $\left| \underline{v}_g \right|$ enables the cutoff Eq. (16) to be used in terminating an abort burn.

Now consider Eq. (6). Set c = 0; then

$$\underline{a}_{T_D} * \underline{v}_g = 0 \tag{31}$$

If the direction of $\underline{v}_g$ is chosen as the desired and known direction of $\underline{a}_T$, the specified constraint on the spacecraft attitude will be satisfied.

Figure 5-1 shows the geometry of the spacecraft window. The angle ϕ between the thrust and $\underline{r}$ is given by

$$\phi = \theta + \sin^{-1} \left(\frac{R_{vh}}{\left| \underline{r} \right|} \right) \tag{32}$$

where θ is the specified angle (35^o) to the horizon and R_{vh} is the radius to the visual horizon.

From Eq. (32) and Eq. (30)we can defined $\underline{v}_g$ as,

$$\underline{v}_g = \frac{d}{\Delta d} \left| \Delta v \right| (-\cos \phi \ \underline{i}_r + \sin \phi \ i_{H'}) \tag{33}$$

5.3.2 Yaw and Roll Steering

The development of Eq. (33) is based on $\underline{i}_r$ and $\underline{i}_H$, which are both in the present trajectory plane according to Eq. (23). However, normally, a plane change will be required to reach the same landing site from different points of aborts on the boost trajectory.

Let the plane containing the present position $\underline{r}$ and the target vector (See Section 5.3.1) $\underline{r}_T$ be defined by

$$\underline{i}_N = \text{UNIT}\ (\underline{r} * \underline{r}_T)\ \text{Sign}\ [(\underline{r} * \underline{r}_T) \cdot \underline{i}_w] \tag{34}$$

The velocity increment along $\underline{i}_p$ (normal to $\underline{v}$) to null the error between $\underline{i}_p$ and $\underline{i}_N$ is given by (See Fig. 5-2).

$$\Delta v_N = |\underline{v}|\ (\underline{i}_p * \underline{i}_N) \cdot \underline{i}_r \tag{35}$$

which is equivalent to:

$$\Delta v_N = |v|\ (-\underline{i}_H) \cdot \underline{i}_N$$

The acceleration along $\underline{i}_p$ required to accomplish the plane change is given by

$$\underline{a}_N = \underline{i}_p \quad \frac{\Delta v_N}{T_g + \delta} \tag{36}$$

where δ is a small scalar (5 seconds). In order to prevent large yaw rate commands, a limit of 8 ft/sec^2 is imposed on the magnitude of $\underline{a}_N$.

Equation (33) can be now modified to include yaw steering, as

$$\underline{v}_g = \underline{i}_T\ \frac{d}{\Delta d}\ |\Delta V| \tag{37}$$

where

$$\underline{i}_T = \text{UNIT}\ \left[-\underline{i}_r \cos\phi + \text{UNIT}\,(\underline{i}_H\ a_T \cos 20^\circ + a_n) \sin\phi\right] \tag{38}$$

and a_T is the magnitude of the thrust acceleration, and the cos 20 term compensates in part for the approximation of projecting the thrust vector onto the horizontal plane.

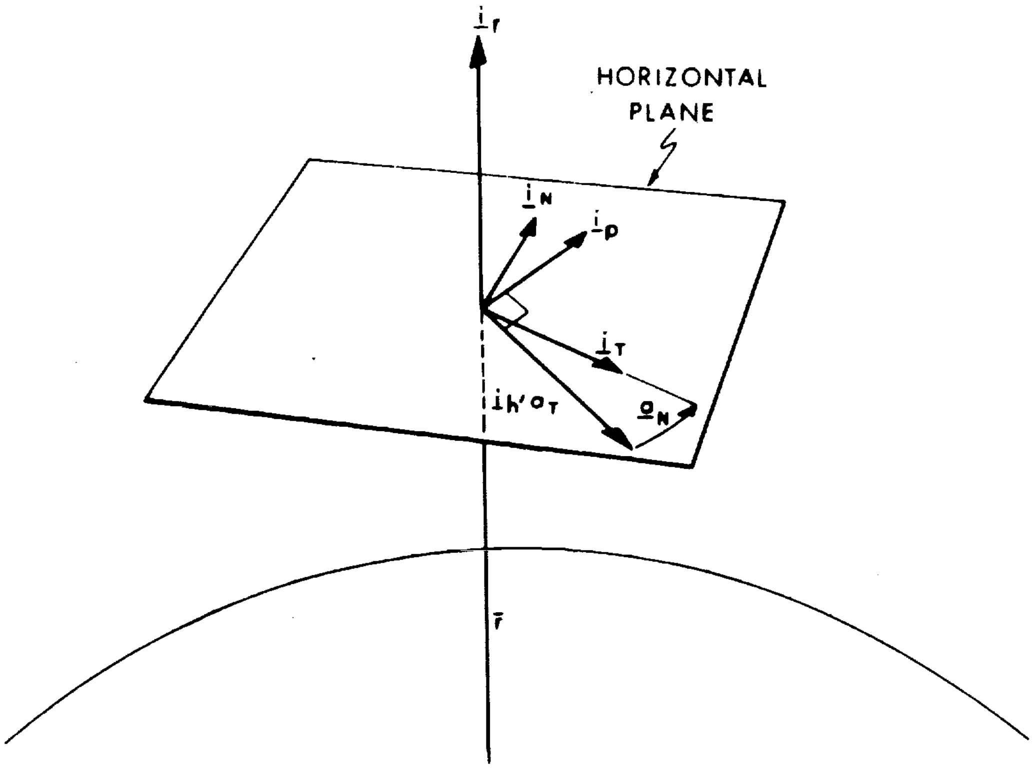


Fig. 5-2 Computation of $\underline{a}_n$ and $\underline{i}_t$

The required velocity is given by

$$\underline{v}_r = \underline{v} + \underline{v}_g \tag{39}$$

where $\underline{v}_g$ is given by Eq. (37). With the required velocity so computed and with c = 0, the same steering (Eq. 6) as for the nominal mission is used.

The rate command resulting from the required velocity $\underline{v}_r$ has only pitch and yaw components. However, the vehicle must be rolled such that the pitch axis is in the horizontal plane (See Fig. 5-2). This is achieved by generating a roll command ($\underline{\omega}_R$) proportional to the cross product of the desired pitch-axis vector, unit ($\underline{r}$* $\underline{i}_{roll}$), with the actual pitch axis unit vector, $\underline{i}_{pitch}$.

$$\underline{\omega}_R = K_{roll} \left[\underline{i}_{roll} \cdot \left(\underline{i}_{pitch} * \text{UNIT}[\underline{r} * \underline{i}_{roll}] \right) \right] \underline{i}_{roll} \tag{39a}$$

where K_{roll} = 0.05 for 202.

The roll rate command is added to the rate command generated from Eq. (7).

5.3.3 Engine Ignition

In the case of a non-tumbling abort the engine is ignited 3.0 secs after receipt of the SIVB/CSM separation signal.

If tumbling has been detected by the time the separation signal is received, the engine is ignited 3.0 secs later and is shut down when tumbling has been arrested. If the capability of landing area control exists, the engine is re-ignited after completion of the maneuver commanded to orient to the desired initial thrust direction.

5.3.4 Engine Cutoff

When T_g falls below 4.0 secs, the clock is set to turn off the engine T_g seconds later under normal area control. However, the engine will be turned off if any one of the following violations has occurred before $T_g < 4.0$ secs.

a) Free-fall time to 400,000 ft* is below 160 seconds

b) $\underline{r}_e$ is beyond $\underline{r}_T$. That is,

$$\underline{r} \cdot \underline{r}_e < \underline{r} \cdot \underline{r}_T \tag{40}$$

c) If term in square brackets in Eq. (22) is negative, (i.e. if $\cot^2 \gamma_e$ is negative).

d) If the free-fall angle θ_f exceeds 53.13^o (i.e. if x in Eq. (17) exceeds 1/2).

5.4 AGC Computations

Since the information about the thrust acceleration comes from the accelerometers in the form of velocity increments (Δv), the computations in the AGC are in terms of increments of velocity rather than instantaneous acceleration. The repetetive guidance computations are shown in the form of a block diagram in Fig. 5-3. The computational blocks are common to all powered flight maneuvers except the computation of $\underline{v}_r$ described in the preceeding sections.

5.4.1 Average g Equations

The vector position and velocity are updated in each computational cycle with a set of equations based on the average gravitational acceleration written as

$$\underline{r}_n = \underline{r}_{n-1} + \Delta t \left(\underline{v}_{n-1} + \underline{g}_{n-1} \frac{\Delta t}{2} + \frac{\Delta \underline{v}}{2} \right) \tag{46}$$

$$\underline{g}_n = \frac{-\mu}{r_n^2} \left[\left[1 + \left(\frac{r_e}{r_n} \right)^2 J(1 - 5 \sin^2 \phi) \right] \underline{i}_{r_n} + \left(\frac{r_e}{r_n} \right)^2 2J \sin \phi \ \underline{i}_W \right] \tag{47}$$

*280,000 ft. in case of aborts during boost phase.

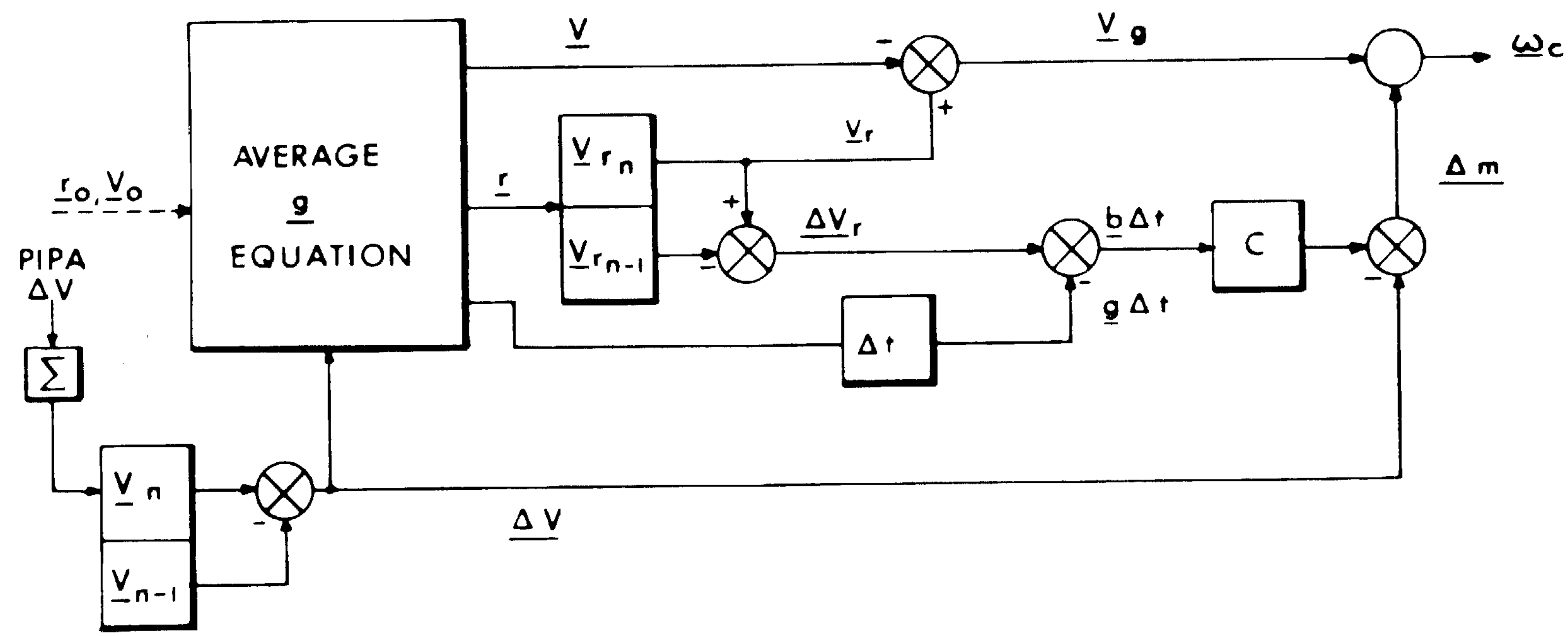


Fig. 5-3 Block Diagram of AGC Guidance Computations

and

$$\underline{v}_n = \underline{v}_{n-1} + \frac{(\underline{g}_{n-1} + \underline{g}_n)}{2} \Delta t + \Delta \underline{v} \qquad (48)$$

where the subscript n denotes the nth computational repetition.

$J = 1.62346 \times 10^{-3}$, the first gravitation harmonic coefficient.

$\sin \phi$ = sin (Geocentric Latitude)

$= \underline{i}_{r_n} \cdot \underline{i}_w$

5.4.2 Steering Command

The vector $\underline{b}$ was defined in Eq. (5) as

$$\underline{b} = \dot{\underline{v}}_r - \underline{g} \qquad (5)$$

In the AGC (as shown in Fig. 5-3), the increment ($\underline{b}\,\Delta t$) is computed as

$$\underline{b}\,\Delta t \cong \Delta \underline{v}_r - \underline{g}\,\Delta t \qquad (49)$$

Then the steering command in Eq. (7) can be written as

$$\Delta \underline{\theta}_c = \frac{\underline{v}_g * \Delta \underline{m}}{|\underline{v}_g||\Delta \underline{m}|} \Delta t \qquad (50)$$

where

$$\Delta \underline{\theta}_c = \underline{\omega}_c \; \Delta t \qquad (51)$$

$$\Delta \underline{m} = c\, \underline{b}\, \Delta t - \Delta \underline{v} \qquad (52)$$

Before being output to the attitude control system, the steer law command is modified as follows:

$$\Delta \underline{\theta}_{out} = K_1 \Delta \underline{\theta}_c + K_2 \Sigma \Delta \underline{\theta}_c$$

For 202 $K_1 = 1/8$, $K_2 = 1/100$, and the second term is limited in magnitude to 1^o.

5.4.3 Orbital Integration Equations

Position and velocity during the free-fall phases of the mission are calculated by a direct numerical integration of the equations of motion. Since the disturbing accelerations are small the technique of differential acceleration due to Encke is mechanized in the AGC, as described in MIT Report R-467, The Compleat Sunrise.

5.5 Initial Thrust Alignment

Before the engine is ignited for any particular maneuver, the vehicle should be oriented so that on ignition the thrust is in the desired direction at that point. Since the time of ignition is known beforehand, the position and velocity at ignition can be computed prior to the arrival of the vehicle at that point. By integrating over Δt seconds from that point, the vectors $\underline{v}_g$ and $\underline{b\Delta t}$ can be computed as shown in Fig. 5-3.

The desired thrust direction can be now calculated (prior to arrival at the ignition point) as

$$\underline{i}_T = \text{UNIT} \left[\underline{q} + (a_T^2 - \left| \underline{q} \right|^2)^{1/2} \underline{i}_g \right] \tag{53}$$

where

$$\underline{i}_g = \text{UNIT} \ (\underline{v}_g) \tag{54}$$

and

$$\underline{q} = c\underline{b} - (\underline{i}_g \bullet c\underline{b})\underline{i}_g \tag{55}$$

and a_T is an estimate of the magnitude of the thrust acceleration.

Once $\underline{i}_T$ is computed from Eq. (53), the vehicle is oriented prior to arrival at the ignition point such that the thrust axis is along $\underline{i}_T$, and the pitch axis is along the desired pitch axis vector, UNIT ($\underline{r} * i_{roll}$) i.e. a wings-level, z(yaw) - axis up roll attitude, using the general attitude maneuver program described in 5.6.

5.6 Attitude Maneuvers

5.6.1 Technique

The technique of computing large attitude maneuver sequences with the Block I G&N System depends on the geometry of Fig. 5-4 and 5-5.

Briefly:

1. A pure spacecraft roll (rotation about $\underline{X}_{SC}$) will force $\underline{X}_{NB}$ to describe a cone of half angle 33° about $\underline{X}_{SC}$ (See Fig. 5-4).

2. Gimbal lock is arbitrarily defined to occur when the outer gimbal axis (OGA, $\underline{X}_{NB}$) cuts into a cone of half angle 30° about the inner gimbal axis (IGA, $\underline{Y}_{SM}$). This condition results in a middle gimbal angle exceeding 60° (See Fig. 5-5).

Because the 33° cone can enclose the 30° cone, it is possible to attain any attitude of the S/C X-axis by specifying the appropriate vehicle roll attitude that avoids gimbal lock.

Maneuvers are performed as combinations of pure S/C roll sequences and S/C pitch/yaw sequences. An attempt is always made to achieve the desired orientation of the S/C X-axis with a planar pitch/yaw rotation from the present orientation. If $\underline{X}_{NB}$ were to cut into the lock area during this maneuver, the sequence is recomputed to include a roll to reposition $\underline{X}_{NB}$ before the pitch/yaw maneuver.

A final roll is always made to attain the desired final roll attitude.

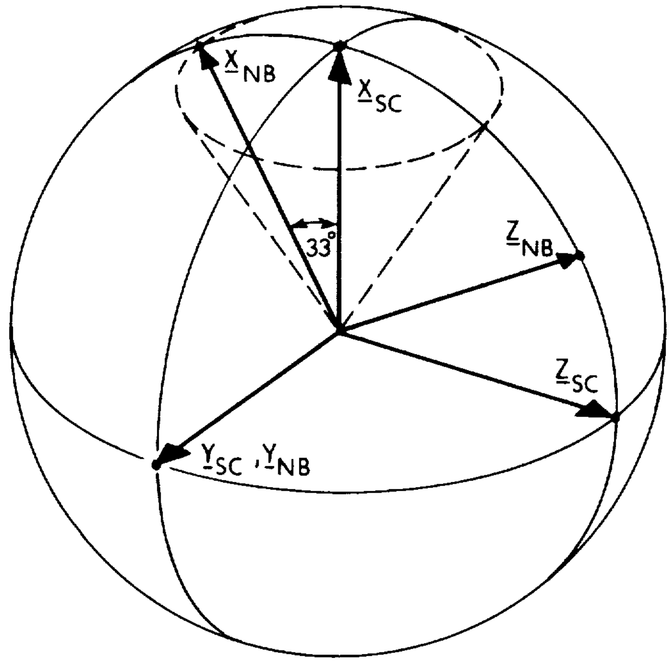


Figure 5-4

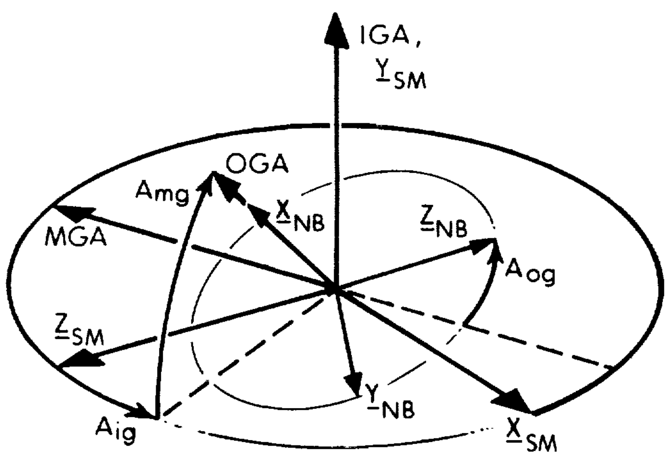


Figure 5-5

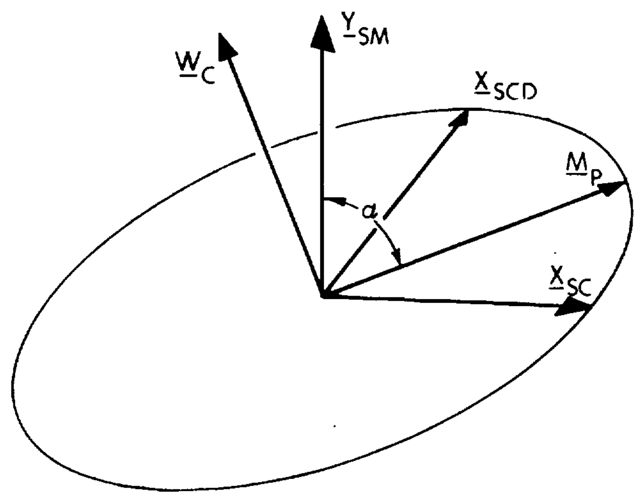


Figure 5-6

Under some extreme conditions it is not possible to avoid gimbal lock with a roll, pitch/yaw, roll sequence. In these cases it becomes necessary to perform more than one pitch/yaw sequence, with attendant additional roll sequences.

5.6.2 Method of Analysis

S/C attitudes are specified with unit vectors. Maneuvers are defined be vector cross-products, and therefore normally follow the shortest route. Let

$$\underline{X}_{SC} = \text{present S/C roll axis}$$

$$\underline{X}_{SCD} = \text{desired S/C roll axis}$$

Plane of pitch/yaw maneuver is defined by

$$\underline{W}_C = \text{unit} (\underline{X}_{SC} * \underline{X}_{SCD}) \tag{56}$$

This plane is closest to Y_{SM} at "max point" M_p (Fig. 5-6) defined by vector

$$\underline{M}_p = \text{UNIT} (\underline{W}_C * \underline{Y}_{SM}) * \underline{W}_C)) \tag{57}$$

If angle $\alpha \geq 63^o$ (i.e. $33^o + 30^o$), then gimbal lock is impossible, and the planned pitch/yaw can be done without an initial roll. If $\alpha < 63^o$ the 33^o cone will cut or enclose the 30^o, and certain roll attitudes will become illegal, depending on the direction of motion, as demonstrated by the heavy arcs of Figs. 5-7 through 5-11. The circles are the intersections of the 30^o and 33^o cones with the unit sphere.

It is now necessary to examine the conditions at each end of the trajectory to determine the correct roll attitude to be used.

If $\underline{X}_{SC}$ were to pass through a max point on the way to the desired attitude, the condition of Fig. 5-7 pertains. That portion of the arc on the 33^o circle which allows acceptable positions of $\underline{X}_{NB}$ is marked by a "normal" begin limit NB, and a "normal" end limit NE. These are referenced from the positive trajectory direction by positive rotations NBL and NEL about $\underline{M}_p$. The trajectory of Fig. 5-8 demonstrates the existence of two acceptable arcs NB_1 NE_1 and NB_2NE_2, defined by four normal limit angles NBL_1, NEL_1, NBL_2 and NEL_2.

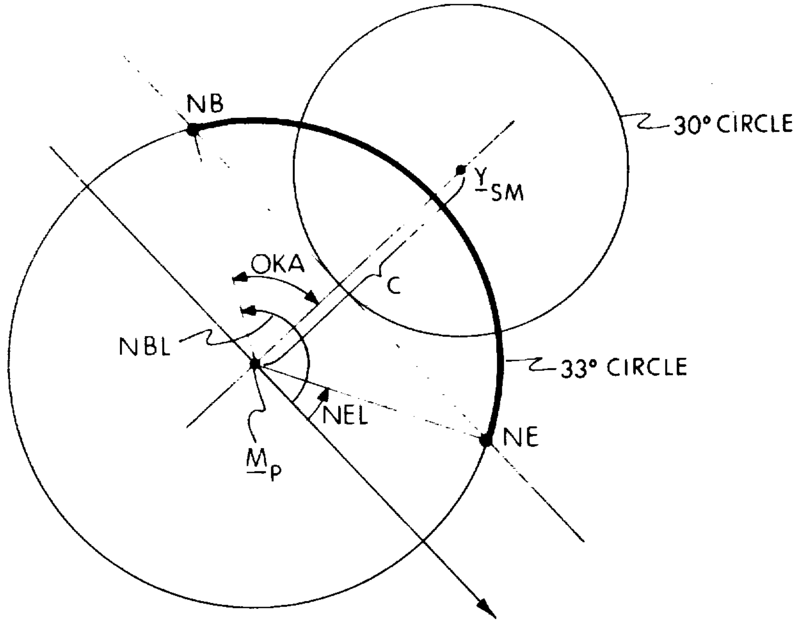


Figure 5-7

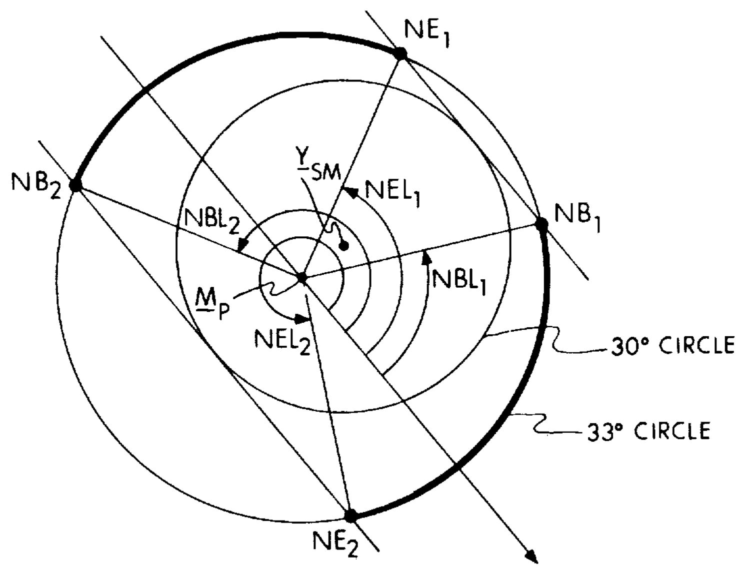


Figure 5-8

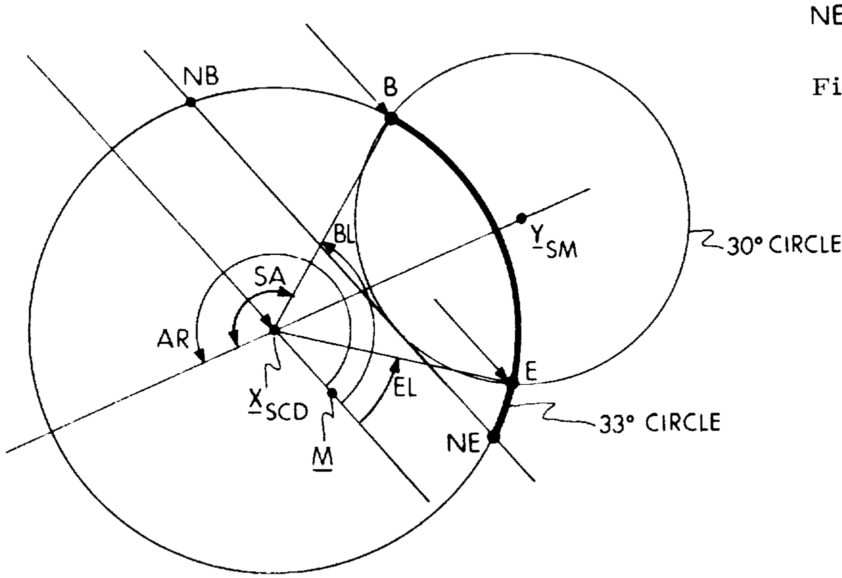


Figure 5-9

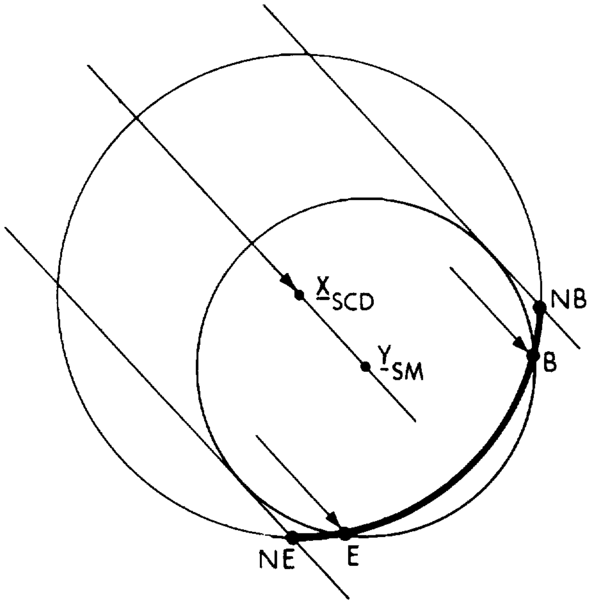


Figure 5-10

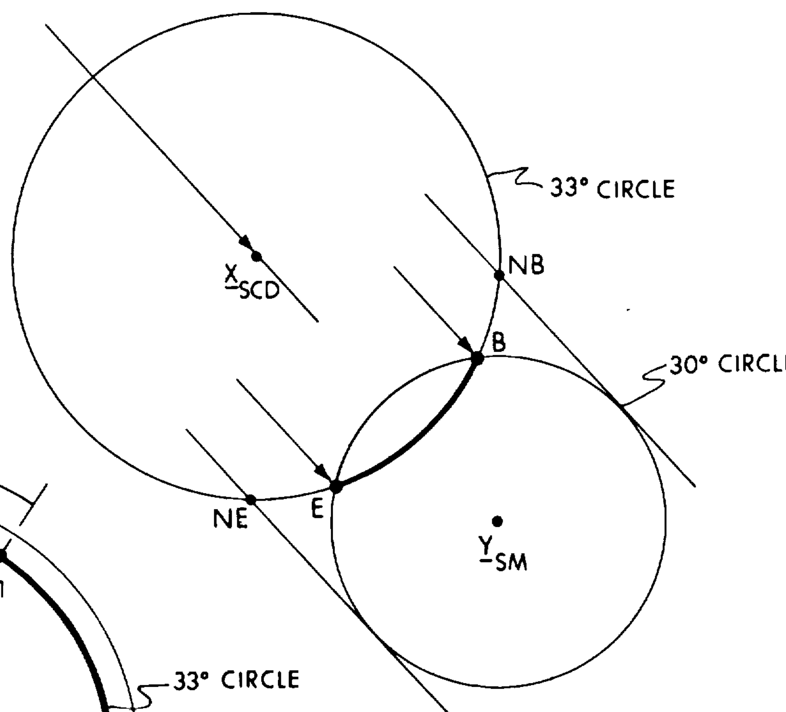


Figure 5-11

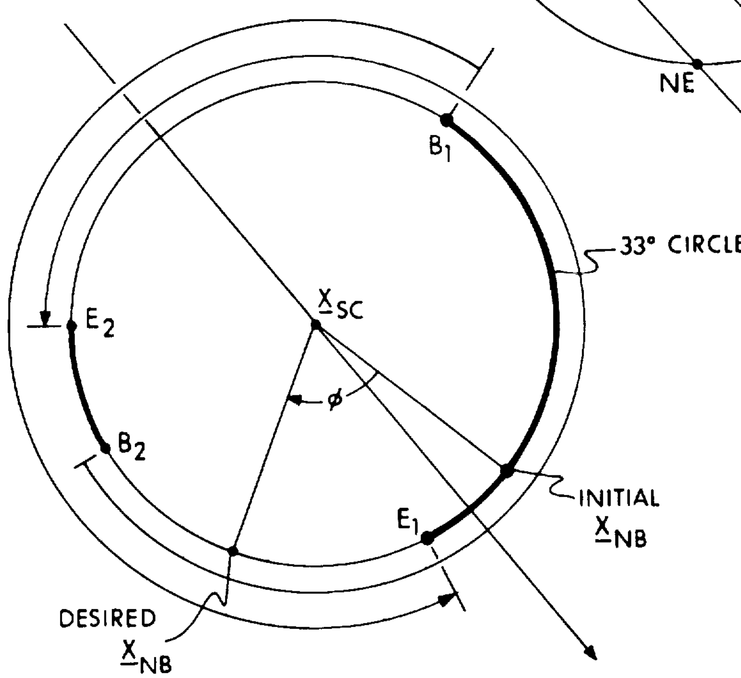


Figure 5-12

The general expression for a normal limit angle is:

$$N(B, E)\ L = \pm\ 180^{\circ} \pm 90^{\circ} + OKA \qquad (58)$$

where

$$OKA = \cos^{-1} (\tan (30^{\circ} - c)/\tan 33^{\circ}) \qquad (59)$$

and c is the angle between $\underline{M}_{p}$ and $\underline{Y}_{SM}$ (See Fig. 5-7).

The signs in Eq. (58) are determined by the geometry of the maneuver.

For motion of $\underline{X}_{SC}$ through a max point the normal limits clearly define regions on the 33° circle where $\underline{X}_{NB}$ is acceptable.

For the condition where the trajectory does not pass through a given max point, but either end of the trajectory lies close to the max point, other limit points can be used to define the acceptable portions of the arc. Figure 5-9 depicts a final desired position $\underline{X}_{SCD}$ for which the 30° and 33° circles intersect. The heavy portions of the arc are unacceptable regions for $\underline{X}_{NB}$.

To define the arc, two "end" limits are specified as the intersections of the 30° and 33° circles. Using the direction of motion as a reference line and the convention of positive rotation about $\underline{X}_{SCD}$ the two "end" limit angles in Fig. 5-9 are given by:

$$BL = AR - SA \qquad (60)$$

$$EL = AR + SA \qquad (61)$$

where AR is measured to a line from $\underline{X}_{SCD}$ pointing away from $\underline{Y}_{SM}$, SA is always positive, and angles may exceed 2π.

For the condition of Fig. 5-9, B is acceptable as a limit. E is not acceptable because during the maneuver it will cross the forbidden area inside the 30° circle. E is said to be a "shaded" limit, and this end of the arc must be defined by the normal limit NE, whose locus is the tangent to the 30° circle.

Other end conditions can result in both limits being "shaded", so that the "normal" limits must be used to define the acceptable arc (See Fig. 5-10), or in neither limit being shaded (See Fig. 5-11), so that both can be used to define the arc.

Figures 5-9, 5-10, and 5-11 can be used to describe conditions at the beginning of the trajectory by replacing $\underline{X}_{SCD}$ with $\underline{X}_{SC}$ and reversing the direction of motion.

To determine the roll attitude necessary for a given maneuver the following steps are taken:

1) Determine if trajectory includes a max point. If it does, compute and save the normal limit angles.
2) Determine if either end of the trajectory is within 63^o of $\pm \underline{Y}_{SM}$ (i.e. do 30^o and 33^o cones intersect the beginning or the end of the trajectory?)

If the results of steps (1) and (2) are both "no" the planned pitch/yaw maneuver can be made without an initial roll, and steps (3) through (10) can be skipped.

3) If step (2) yields a "yes", determine if the beginning of the trajectory is within 63^o of $\pm \underline{Y}_{SM}$. If it is not, skip to step (5). If it is, determine whether $\underline{X}_{SC}$ will move toward or away from the max point. If towards, the max point has already been determined in step (1) and its normal limits saved. If away from, compute the end limits for the beginning of the trajectory. (If the result of step (1) was "no", motion of $\underline{X}_{SC}$ towards a max point is a special case. Since $\underline{X}_{SCD}$ is closer to gimbal lock than $\underline{X}_{SC}$, its limits will include those associated with $\underline{X}_{SC}$, and steps (3) and (4) may be omitted).
4) Determine if either of the end limits computed in step (3) is "shaded" or not. If shading exists, replace either or both end limits with the corresponding normal limits, and save the results.
5) If step (2) yielded a "yes", determine if the end of the trajectory is near a max point. If it is, determine whether this max point is on the trajectory (i.e. if it has already been covered in step (1)). If not, compute the end limits for the end of the trajectory.
6) Repeat step (4) for the end limits of step (5).
7) Combine the limit angles computed in steps (1) through (6) and determine those portions of the 33^o circle that are acceptable throughout the trajectory.

At this point the 33^o circle can be mapped out for acceptable and non-acceptable arcs. This has been done for a random example in Fig. 5-12. Acceptable portions of the circle as determined by steps (1) through (6) are the arcs $B_1 E_1$ and $B_2 E_2$. Only those portions where acceptable arcs overlap are allowed for $\underline{X}_{NB}$, i.e. arcs $B_1 E_2$ and $B_2 E_1$.

8) Determine if the initial roll attitude is such that the position of $\underline{X}_{NB}$ on the 33^{o} circle is acceptable. If it is, no initial roll is needed. If it is not, specify a desired $\underline{X}_{NB}$ position midway on an overlapping region.

9) Define a roll maneuver ϕ so that $\underline{X}_{NB}$ will move around the 33^{o} cone the shorter way to its desired position. (See Fig. 5-11).

10) Check if the roll maneuver of step (9) forces $\underline{X}_{NB}$ to move into the 30^{o} cone around $\underline{Y}_{SM}$. If it does, reverse the direction of the roll and cause $\underline{X}_{NB}$ to move the longer way around the 33^{o} cone.

11) Following the completion of the roll maneuver, perform the pitch/yaw maneuver defined in direction by Eq. (56) and in magnitude by

$$\theta = \left\{ \begin{array}{l} \sin^{-1} \left(\left| \underline{X}_{SC} * \underline{X}_{SCD} \right| \right) \\ \\ \cos^{-1} \left(\left| \underline{X}_{SC} \cdot \underline{X}_{SCD} \right| \right) \end{array} \right\} \qquad (62)$$

If the results of step (7) indicate that there are no overlapping acceptable arcs, the planned single pitch/yaw maneuver cannot be done. In this case the maneuver is "split" into two equal co-planar pitch/yaw maneuvers. $\underline{X}_{NB}$ is rolled mid-way into the acceptable region associated with the start of the trajectory and half the pitch/yaw is performed. At the start of the second half of the trajectory, the required roll attitudes are re-evaluated from scratch as if the remainder of the pitch/yaw were a fresh maneuver.

For the case where the required pitch/yaw maneuver is greater than 179^{o} Eqs. (56) and (62) are not used to define the trajectory, since $\underline{W}_{C}$ becomes indeterminate in direction. A more convenient choice is made:

$$\underline{W}_{C} = \text{UNIT} \left(\underline{X}_{SC} * \left(\underline{X}_{SC} * \underline{Y}_{SM} \right) \right) \qquad (63)$$

This ensures the greatest angle between $\underline{Y}_{SM}$ and the trajectory plane, minimizing the need for initial roll maneuvers.

5.6.3 Mechanization

The attitude maneuver computations in the AGC are performed by two distinct routines. The first, CALCMANU, analyses the maneuver and generates the sequences of submaneuvers as described in Section 5.6.2. It requires as input the desired orientation of the spacecraft in the form of three unit vectors, $\underline{X}$, $\underline{Y}$, $\underline{Z}_{SCD}$ (along the roll, pitch, yaw axes) expressed in stable member coordinates. The output is a unit vector determining the axis of rotation, W_C (Eq. (56)), the magnitude of the rotation about this axis, θ (Eq. (62)), and a switch setting indicating a roll or a pitch/yaw maneuver.

The second routine, DOMANU, processes these outputs and generates CDU commands to drive the vehicle in the specified manner. For AS-202 spacecraft angular rates are limited in command to 4°/sec. in pitch/yaw and 7.2°/sec. in roll for CSM maneuvers, and 4°/sec. and 15°/sec, respectively, for CM maneuvers. The general expression for a vehicle rate is:

$$\frac{d\theta}{dt} = (4,\ 7.2,\ 15)\ \underline{W}_C \tag{64}$$

Maneuver commands are computed at fixed intervals. Rate equations are therefore expressed in incremental form:

$$\begin{aligned} \underline{\Delta\theta} &= \Delta t\ (4,\ 7.2,\ 15)\ \underline{W}_C \\ &= k\ \underline{W}_C \end{aligned} \tag{65}$$

The quantity k is the magnitude of the output command at each iteration. The command stays at this level until:

$$\theta - \Sigma k \leq k \tag{66}$$

i.e. until the maneuver rotation is less than k degrees from completion. The final increment is then $\theta - \Sigma k$ degrees. The vector $\underline{\Delta\theta}$ expressed in stable member coordinates, is resolved into gimbal (CDU) coordinates, as follows:

$$\begin{aligned} \Delta A_{og} &= \Delta\theta_x - \cos A_{og} \tan A_{mg} \Delta\theta_y + \sin A_{og} \tan A_{mg} \Delta\theta_z \\ \Delta A_{ig} &= \cos A_{og} \sec A_{mg} \Delta\theta_y - \sin A_{og} \sec A_{mg} \Delta\theta_z \\ \Delta A_{mg} &= \sin A_{og} \Delta\theta_y + \cos A_{og} \Delta\theta_z \end{aligned} \tag{67}$$

where a positive gimbal angle increment represents a clockwise rotation of a gimbal about the positive direction of its axis. (See Fig. 5-5 for definition of gimbal axes.)

From the above it can be seen that a maneuver is treated as a constant rate for a fixed time. No attempt is made to modify commands with the inverse responses of either the CDU's or the spacecraft. In order to accomodate the resulting lag in the response of the system, a five-second "settling" period is inserted after each maneuver to allow the spacecraft to settle into the desired orientation. During this 5-second period the program returns to the routine CALCMANU to check that the maneuver was satisfactorily performed, and to provide DOMANU with initial conditions for the next maneuver in sequence.

Due to the noncommutativity of finite angles, the expressions in Eqs. (67) may, for large maneuvers at the higher rates, result in a deviation of the commanded spacecraft axes from the desired trajectory plane. CALCMANU always checks whether $\underline{X}_{SC}$ and $\underline{X}_{SCD}$ are greater than 3 degrees apart. If they are, a "corrective" pitch/yaw maneuver is demanded to bring them into coincidence. DOMANU performs this correction, and eventually returns to CALCMANU. If, finally, the test shows the separation to be less than 3 degrees, CALCMANU computes the exact desired set of gimbal angles and "snaps" the CDU's to these values. The final values are a set of euler angles, θ, ψ, ϕ extracted from the matrix identity:

$$\begin{pmatrix} X_{SCDX} & X_{SCDY} & X_{SCDZ} \\ Y_{SCDX} & Y_{SCDY} & Y_{SCDZ} \\ Z_{SCDX} & Z_{SCDY} & Z_{SCDZ} \end{pmatrix} =$$

$$\begin{pmatrix} \cos 33 & 0 & \sin 33 \\ 0 & 1 & 0 \\ -\sin 33 & 0 & \cos 33 \end{pmatrix} \begin{pmatrix} \cos\phi\cos\psi & \sin\psi & -\sin\theta\cos\psi \\ -\cos\theta\sin\psi\cos\phi + \sin\theta\sin\phi & \cos\psi\cos\phi & \sin\theta\sin\psi\cos\phi + \cos\theta\sin\phi \\ \cos\theta\sin\psi\sin\phi + \sin\theta\cos\phi & -\cos\psi\sin\phi & -\sin\theta\sin\psi\sin\phi + \cos\theta\cos\phi \end{pmatrix} \quad (68)$$

where $\theta = A_{ig}$ (CDUY)

$\psi = A_{mg}$ (CDUZ)

$\phi = A_{og}$ (CDUX)

5.7 Free-Fall Time

Since the free-fall time is not very large, the radial acceleration from cutoff to entry can be assumed constant. With this assumption the equation for the magnitude of the radius can be written as

$$r(T_f) = \ddot{r}\,(0)\ \frac{T_f^2}{2} + r\,(0)\ T_f + r\,(0) \tag{69}$$

where T_f is the free-fall time to the radius $r\,(T_f)$ and $T_f = 0$ corresponds to present time.

Solving Eq. (69) for T_f yields

$$T_f = \frac{-\dot{r}\,(0) - \sqrt{\dot{r}(0)^2 - 2\dot{r}\,(0)\ \ (r(0)' - rT_f)}}{\ddot{r}\,(0)} \tag{70}$$

Setting $r(T_f) = r_e$ in Eq. (70) the time of free-fall to entry is given as

$$T_f = \frac{-\dot{r} - \sqrt{\dot{r}^2 - 2\ddot{r}(r-r_e)}}{\ddot{r}} \tag{71}$$

For certain points on a trajectory the square root in Eq. (71) will be negative. In such cases T_f is set equal to zero. On the other hand, if $\ddot{r}$ is so small, to cause an overflow, T_f is set to the maximum value of $2^{28}/100$ seconds.

5.8 Entry Mode

Included in this section is a set of flow charts that describe the logic and equations that control the entry vehicle. Figure 5-13 shows the overall picture of the sequence of operations during entry. Each block in Figure 5-13 is described in detail in subsequent charts. Table 5-1 defines symbols which represent computed variables stored in the erasable memory. The value and definition of constants is given in Section 6.

Every pass through the entry equations (done once every 2 seconds) is begun with the section called navigation. (See Fig. 5-14). This integrates to determine the vehicle's new position and velocity vector. This subroutine is used by other phases than entry and is called the Average G routine.

Next, the targeting is done. This updates the desired landing site position vector and computes some quantities based on the vehicle's position and velocity and the position of the landing site. (See Fig. 5-15.)

The next sequence of calculations is dependent upon the phase of the entry trajectory that is currently being flown. First is the initial roll angle computation. (See Fig. 5-16.) This merely adjusts the Initial roll angle (180° for a nominal 202 entry; 0° for abort cases) and tests when to start the next phase.

The next phase maintains a constant drag trajectory while testing to see if it is time to go into the up-control phase. The testing is presented in Figs. 5-17 and 5-18. The constant drag equations are given in Fig. 5-19. The other phases (up-control, ballistic and final) are listed in Fig. 5-20, 5-21, and 5-22. The final phase is accomplished by a stored reference trajectory. Its characteristics as well as the steering gains are stored as shown in Fig. 5-23. The routine that prevents excessive acceleration build-up (G limiter) is given in Fig. 5-24. And finally, the section that does the lateral logic calculations and computes the commanded roll angle is shown in Fig. 5-25.

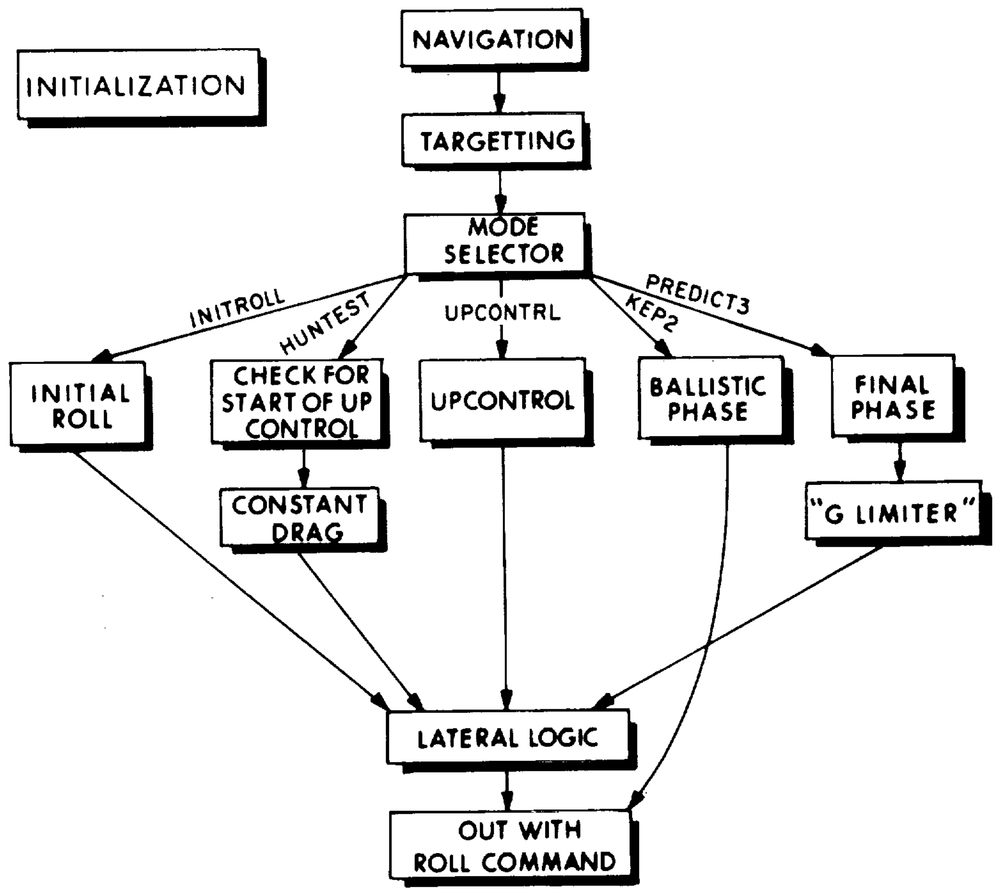


Fig. 5-13 Re-Entry Steering

READ & CLEAR PIPAS
SAVE VEL INCREMENT
AS $\overline{DELV}$

$$\overline{TEM} = \overline{VIN} + \Delta T \, \frac{\overline{G}}{2} + \frac{\overline{DELV}}{2}$$

$$\overline{R} = \overline{R} + \Delta T \, \overline{TEM}$$

$$R = ABVAL(\overline{R})$$

$$SL = UNIT(\overline{R}) \cdot \overline{UZ}$$

$$\frac{\overline{G}}{2} = -\frac{MUE}{2R^2}\left[\left(1 + J\left(\frac{RE}{R}\right)^2 (1 - 5\,SL^2)\right) UNIT(\overline{R}) + 2\,SL\,J\left(\frac{RE}{R}\right)^2 \overline{UZ}\right]$$

$$\overline{VIN} = \overline{TEM} + \frac{\overline{DELV}}{2} + \Delta T \, \frac{\overline{G}}{2}$$

Fig. 5-14 Re-Entry Steering - Navigation (AVG. G)

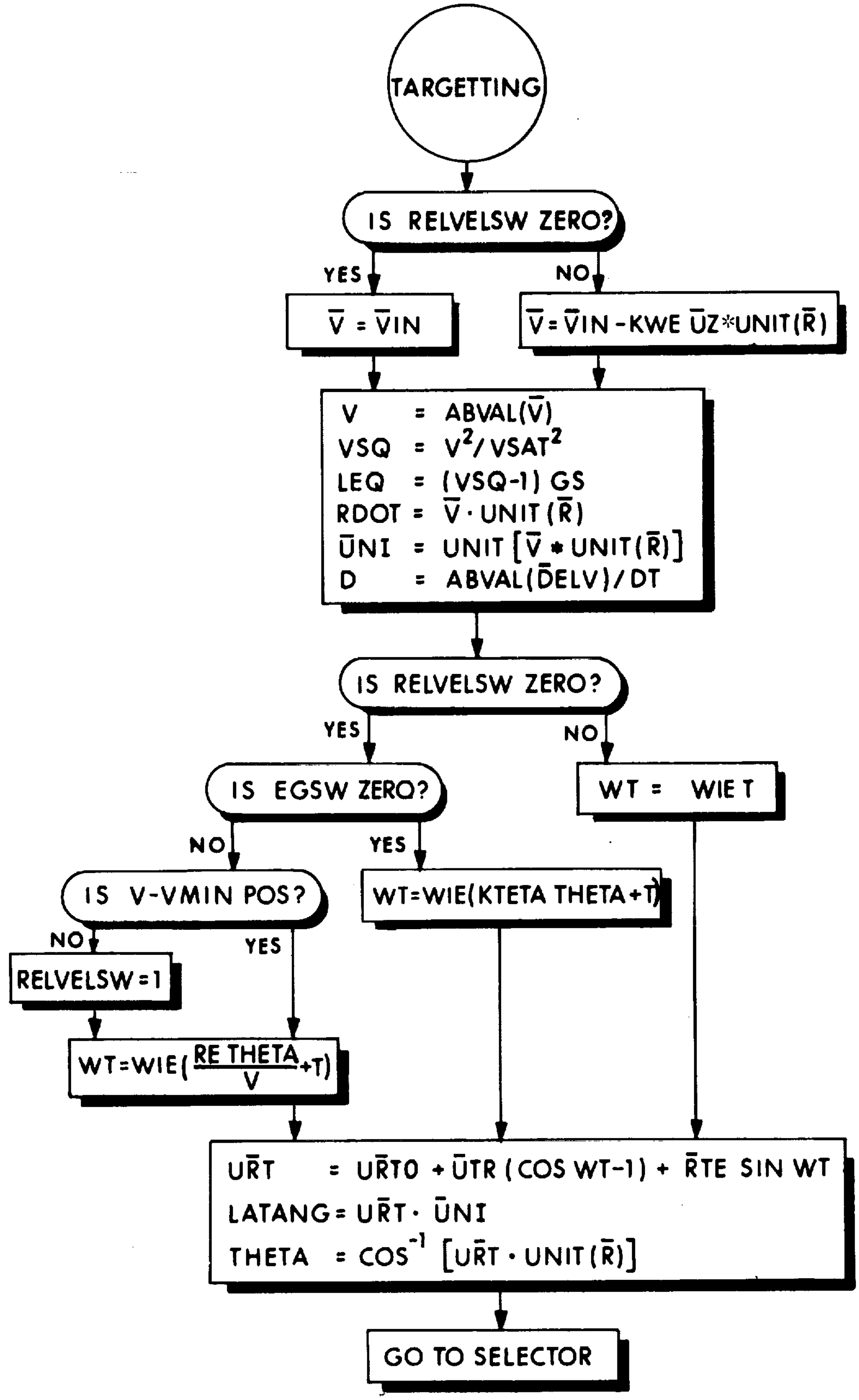


Fig. 5-15 Re-Entry Steering - Targetting

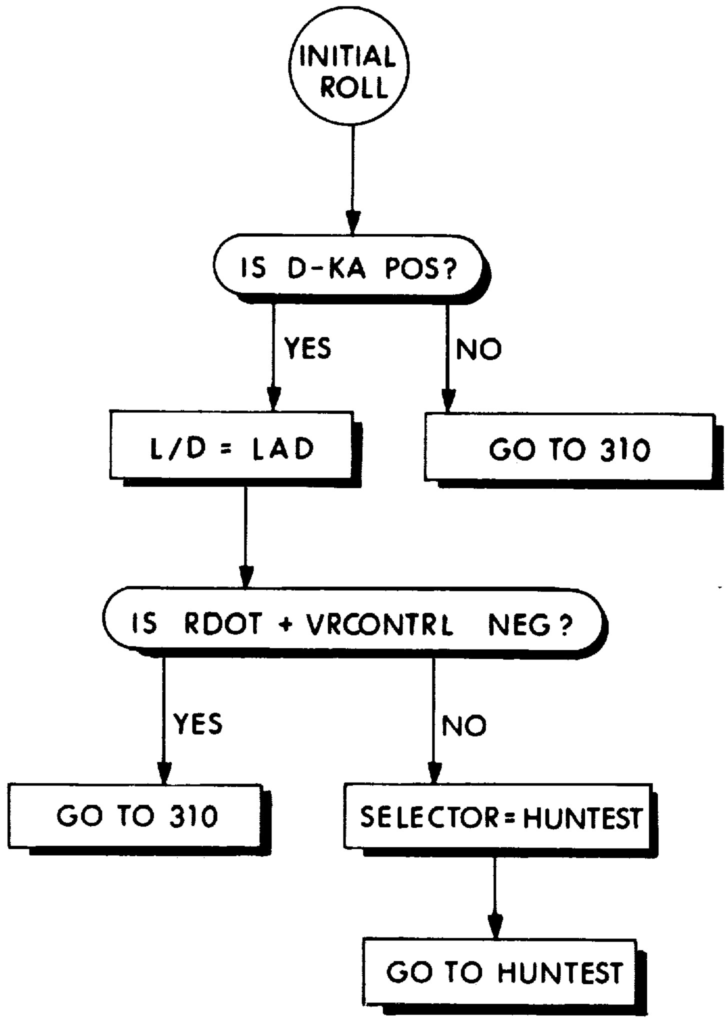


Fig 5-16 Re-Entry Steering - Initial Roll

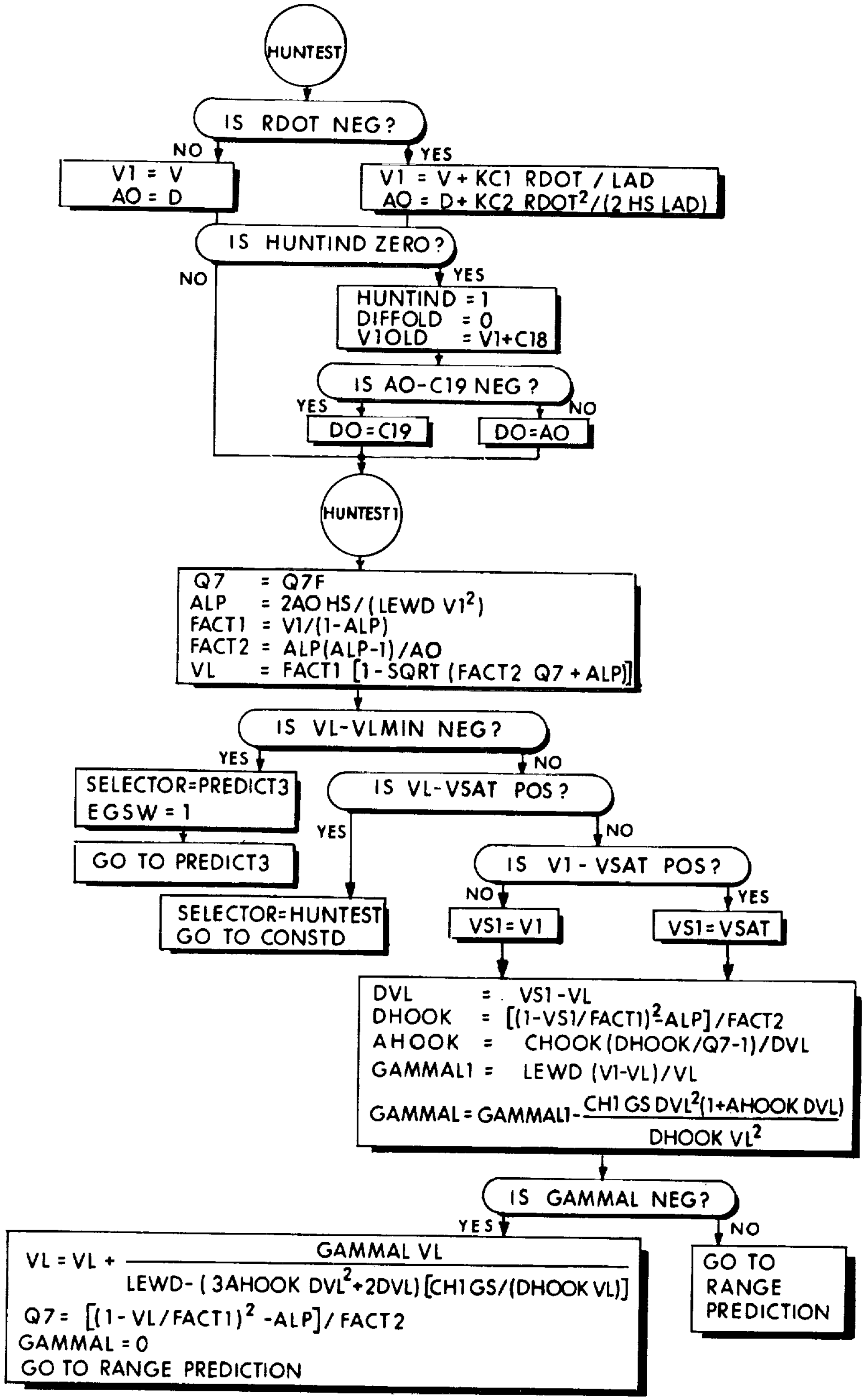


Fig. 5-17 Re-Entry Steering - Huntest

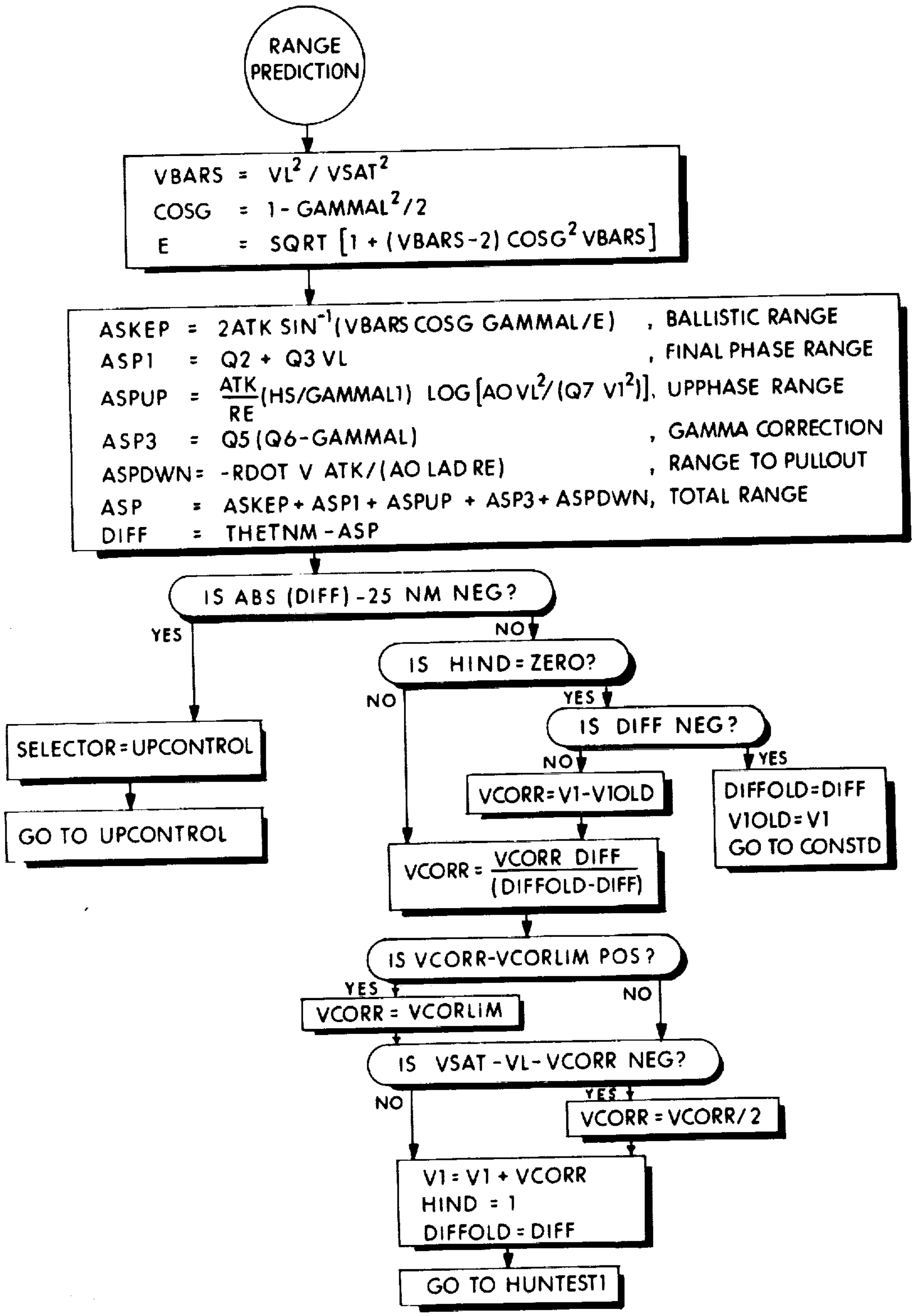


Fig 5-18 Re-Entry Steering - Range Prediction

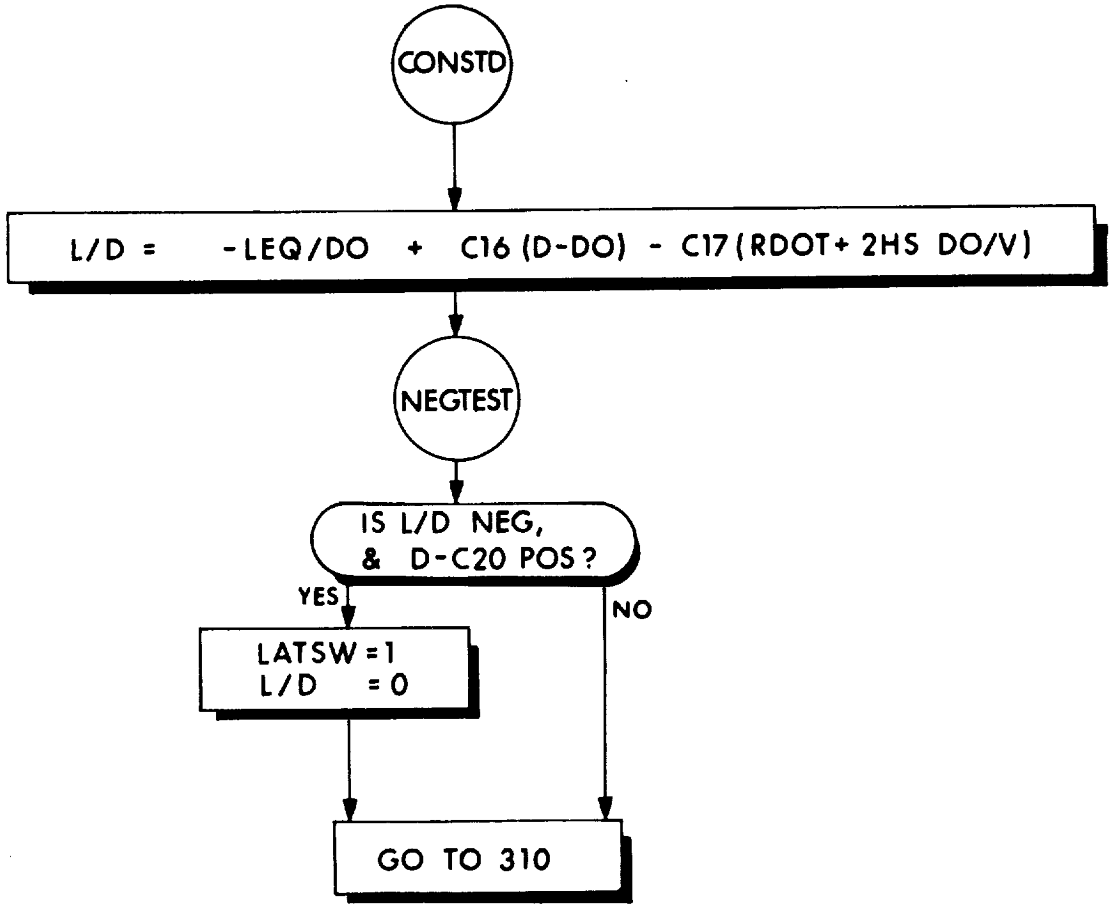


Fig 5-19 Re-Entry Steering - CONSTD

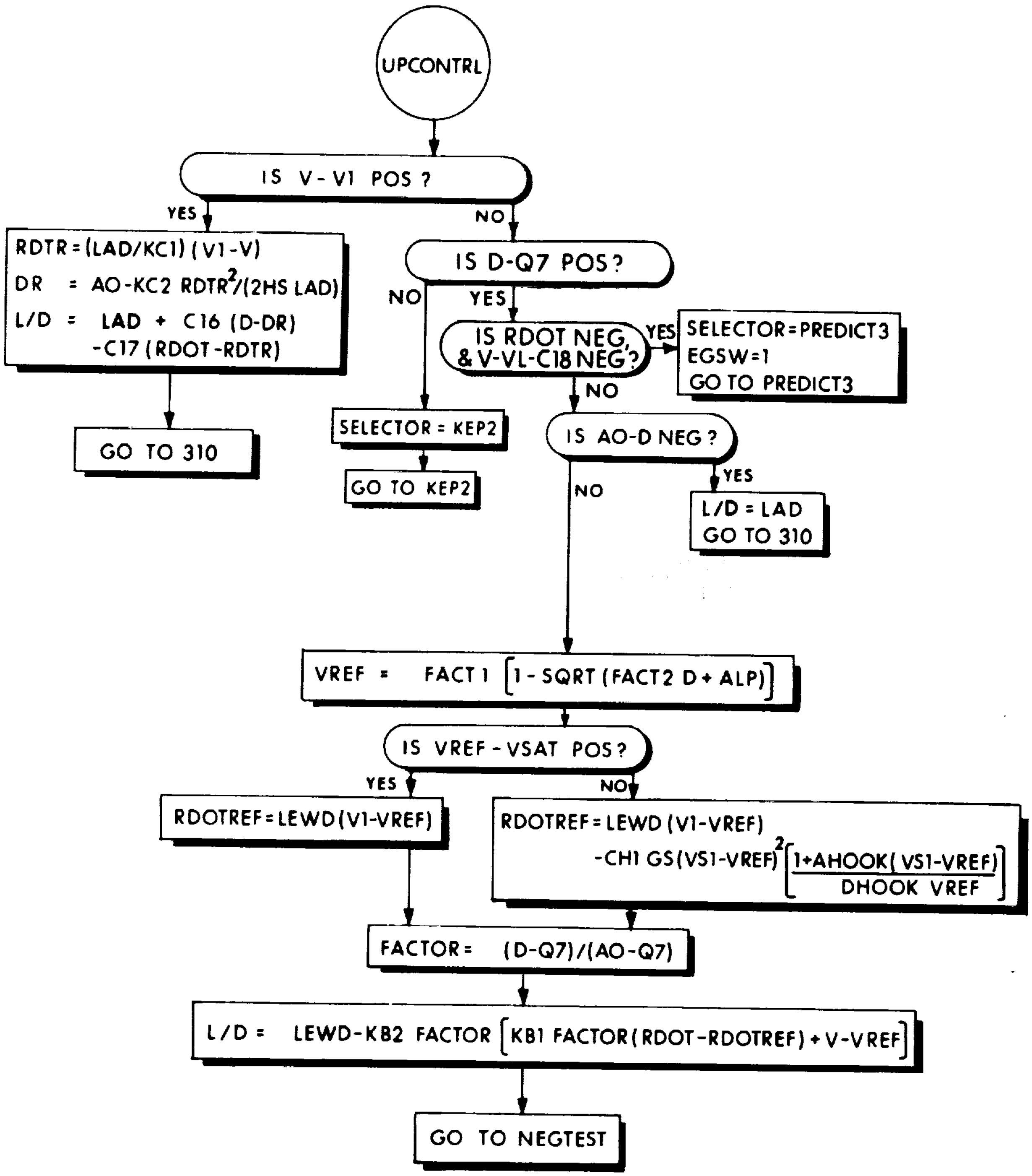


Fig. 5-20 Re-Entry Steering - UPCONTRL

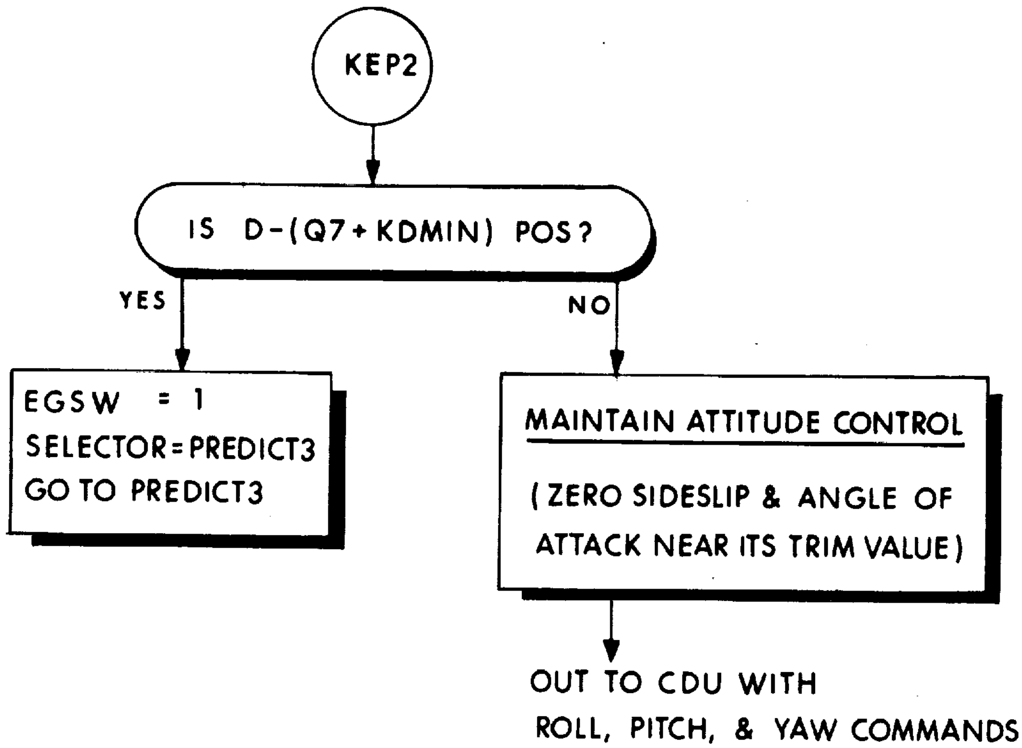


Fig. 5-21 Re-Entry Steering - Ballistic

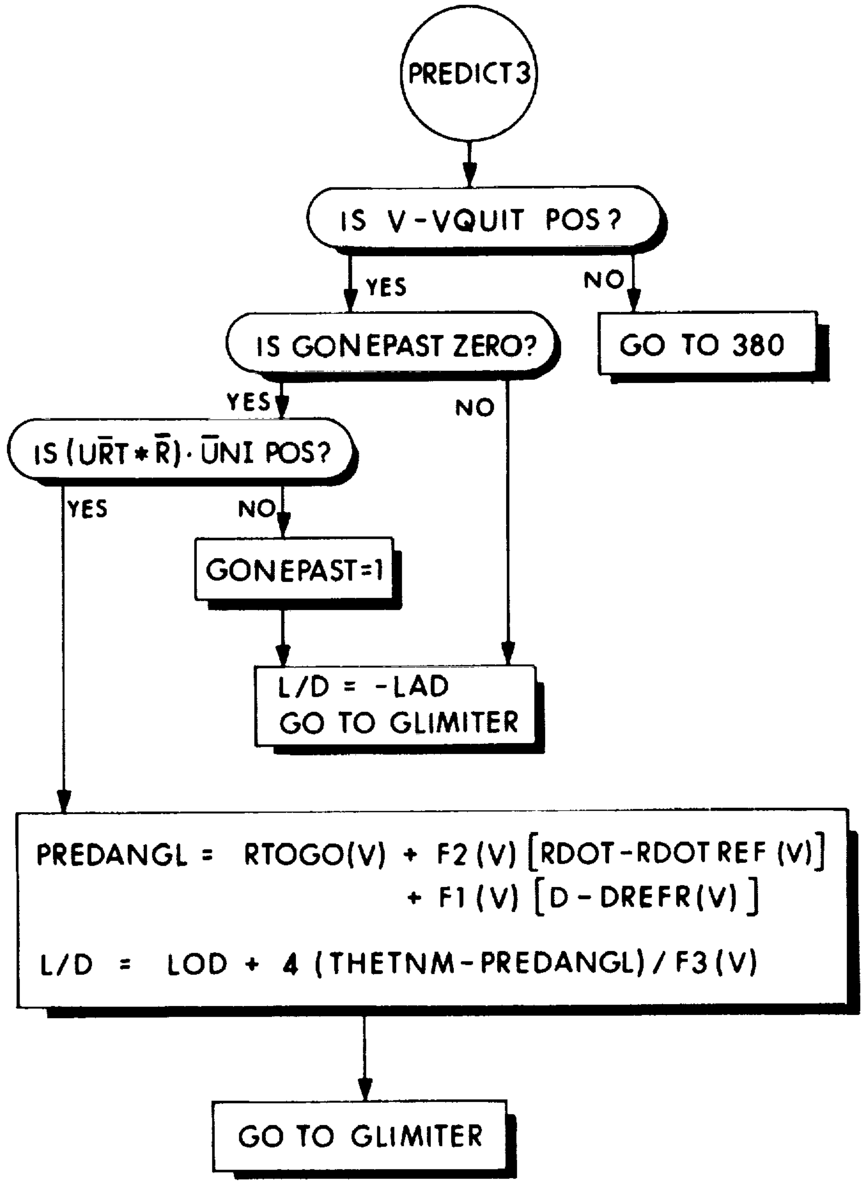


Fig. 5-22 Re-Entry Steering - Predict 3

VREF FPS	RDOTREF FPS	DREFR FPSS	DR/DRDOT F2 NM/FPS	DR/DA F1 NM/FPSS	RTOGO NM	DR/DL/D F3 NM
0	-331	34.1	0	-.02695	0	1
337	-331	34.1	0	-.02695	0	1
1080	-693	42.6	.002591	-.03629	2.7	6.44 x 2
2103	-719	60.	.003582	-.05551	8.9	10.91 x 2
3922	-694	81.5	.007039	-.09034	22.1	21.64 x 2
6295	-609	93.9	.01446	-.1410	46.3	48.35 x 2
8531	-493	98.5	.02479	-.1978	75.4	93.72 x 2
10101	-416	102.3	.03391	-.2372	99.9	141.1 x 2
14014	-352	118.7	.06139	-.3305	170.9	329.4
15951	-416	125.2	.07683	-.3605	210.3	465.5
18357	-566	120.4	.09982	-.4956	266.8	682.7
20829	-781	95.4	.1335	-.6483	344.3	980.5
23090	-927	28.1	.2175	-2.021	504.8	1385
23500	-820	6.4	.3046	-3.354	643.0	1508
35000	-820	6.4	.3046	-3.354	643.0	1508

Fig. 5-22 Final Phase Reference

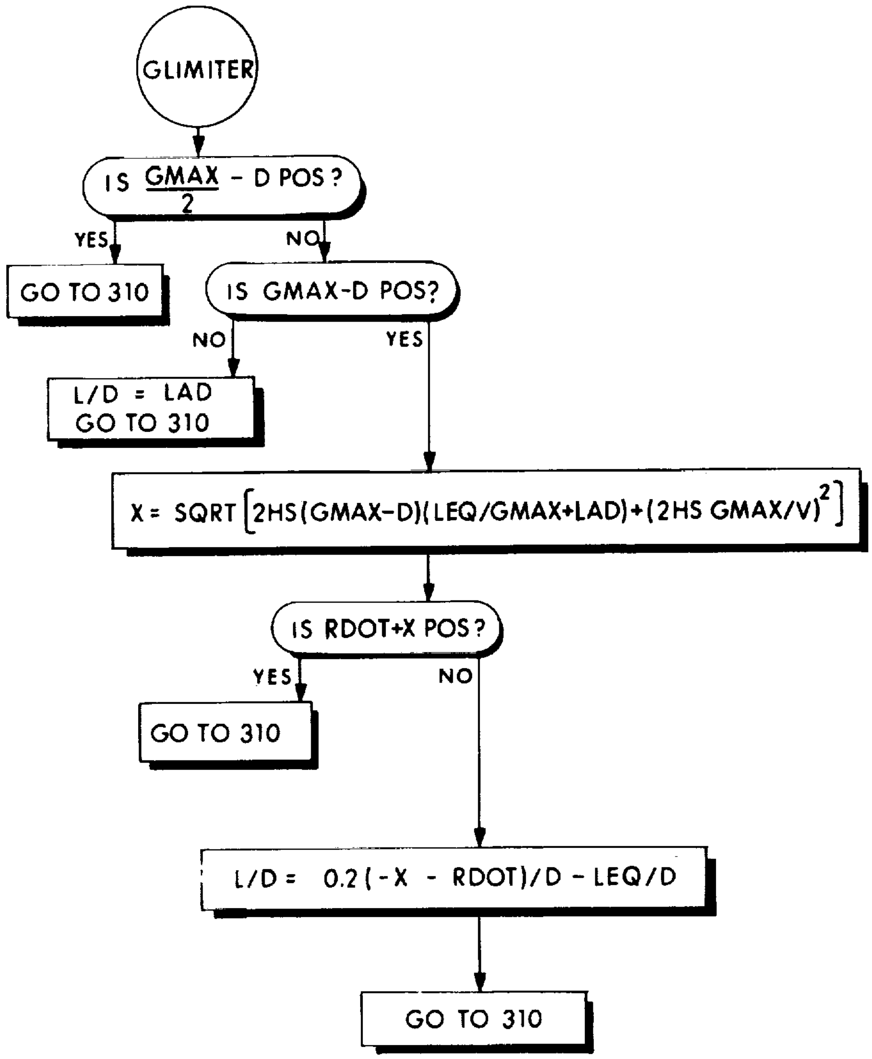


Fig. 5-24 Re-Entry Steering - GLIMITER

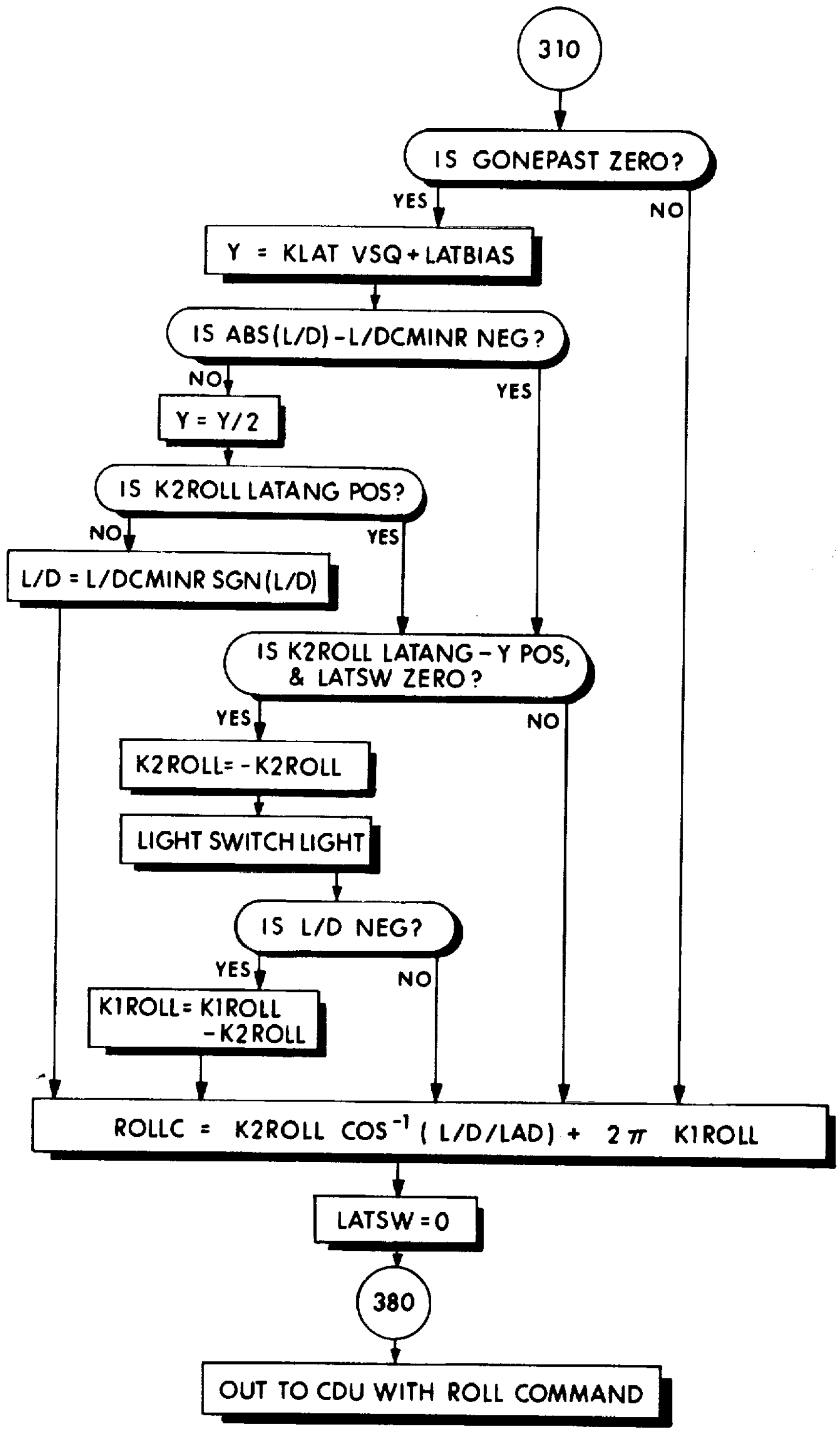


Fig. 5-25 Re-Entry Steering - Lateral Logic

TABLE 5-1

VARIABLES FOR RE-ENTRY CONTROL

$\bar{U}$RTO	INITIAL TARGET VECTOR
$\bar{U}$Z	UNIT VECTOR NORTH
$\bar{V}$	VELOCITY VECTOR
$\bar{V}$I	INERTIAL VELOCITY VECTOR
$\bar{R}$	POSITION VECTOR
$\bar{R}$TE	VECTOR EAST AT INITIAL TARGET
$\bar{U}$TR	NORMAL TO $\bar{R}$TE AND $\bar{U}$Z
U$\bar{R}$T	TARGET VECTOR
$\bar{U}$NI	UNIT NORMAL TO TRAJECTORY PLANE
$\bar{D}$ELV	INTEGRATED ACCELERATION VECTOR
$\bar{G}$	GRAVITY VECTOR
AO	INITIAL DRAG FOR UPCONTRL
AHOOK	TERM IN GAMMAL COMPUTATION
ALP	CONST FOR UPCONTRL
ASKEP	KEPLER RANGE
ASP1	FINAL PHASE RANGE
ASPUP	UPRANGE
ASP3	GAMMA CORRECTION
ASPDWN	RANGE DOWN TO PULL-UP
ASP	PREDICTED RANGE = ASKEP+ASP1+ASPUP+ASP3+ASPDWN
COSG	COSINE (GAMMAL)
D	TOTAL ACCELERATION
DO	CONTROLLED CONST DRAG
DHOOK	TERM IN GAMMAL COMPUTATION
DIFF	THETNM-ASP (RANGE DIFFERENCE)
DIFFOLD	PREVIOUS VALUE OF DIFF
DR	REFERENCE DRAG FOR DOWNCONTROL
DREFR	REFERENCE DRAG
DVL	VS1 -VL

TABLE 5-1 (Cont'd)

E	ECCENTRICITY	
F1	DRANGE/D DRAG	(FINAL PHASE)
F2	DRANGE/DRDOT	(FINAL PHASE)
F3	DRANGE/D(L/D)	(FINAL PHASE)
FACT1	CONST FOR UPCONTRL	
FACT2	CONST FOR UPCONTRL	
FACTOR	USED IN UPCONTRL	
GAMMAL	FLIGHT PATH ANGLE AT VL	
GAMMAL1	SIMPLE FORM OF GAMMAL	
K1ROLL	INDICATOR FOR ROLL SWITCH	
K2ROLL	INDICATOR FOR ROLL SWITCH	
LATANG	LATERAL RANGE	
LEQ	EXCESS C. F. OVER GRAV = (VSQ-1) GS	
L/D	DESIRED LIFT TO DRAG RATIO (VERTICAL PLANE)	
PREDANGL	PREDICTED RANGE	(FINAL PHASE)
Q7	MINIMUM DRAG FOR UPCONTROL	
RDOT	ALTITUDE RATE	
RDOTREF	REFERENCE RDOT FOR UPCONTRL	
RDTR	REFERENCE RDOT FOR DOWNCONTRL	
ROLLC	ROLL COMMAND	
RTOGO	RANGE TO GO	(FINAL PHASE)
SL	SINE OF GEOCENTRIC LATITUDE	
T	TIME	
THETA	DESIRED RANGE (RADIANS)	
THETNM	DESIRED RANGE (NM)	
V	VELOCITY MAGNITUDE	
V1	INITIAL VELOCITY FOR UPCONTRL	
V1OLD	PREVIOUS VALUE OF V1	

VREF	REFERENCE VELOCITY FOR UPCONTRL
VCORR	VELOCITY CORRECTION FOR UPCONTRL
VL	EXIT VELOCITY FOR UPCONTRL
VS1	VSAT OR V1, WHICHEVER IS SMALLER
VBARS	$VL^2/VSAT^2$
VSQ	NORMALIZED VELOCITY SQUARED = $V^2/VSAT^2$
WT	EARTH RATE X TIME
X	INTERMEDIATE VARIABLE USED IN G LIMITER
Y	LATERAL MISS LIMIT

SWITCHES		INITIAL STATE
RELVELSW	RELATIVE VELOCITY SWITCH	(0)
EGSW	FINAL PHASE SWITCH	(0)
HUNTIND	INITIAL PASS THRU HUNTEST	(0)
HIND	INDICATES INTERATION IN HUNTEST	(0)
LATSW	DISABLE LATERAL CONTROL	(0)
GONEPAST	INDICATES OVERSHOOT OF TARGET	(0)

5.8 AGC Entry Programming - Detailed Flow Charts

This section presents flow charts that represent the precise implementation of the entry equations as programmed for the AGC. An attempt has been made to make it as detailed and explicit as possible. However, it is assumed that a user needing this degree of detail has a familiarity with both the basic hardware and software of the AGC.

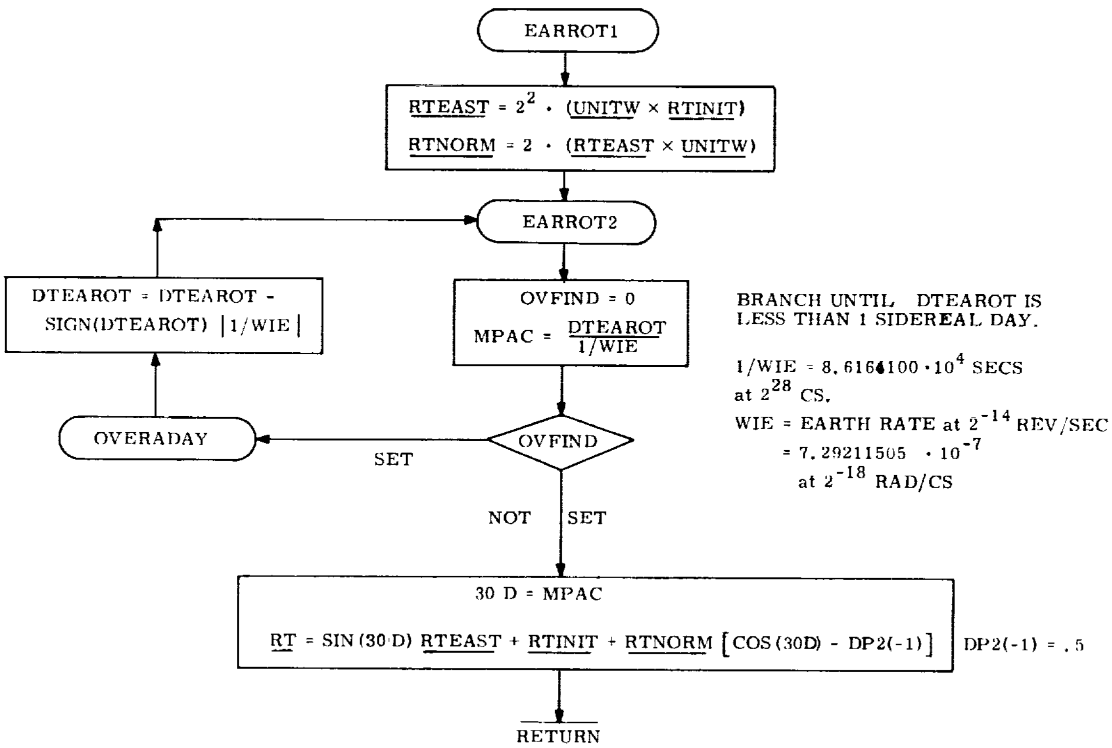
EARROT

FN: RESOLVE THE VECTOR RTINIT THROUGH AN ANGULAR ROTATION WIE(DTEAROT) at 1 REV ABOUT THE UNIT POLAR AXIS UNITW.

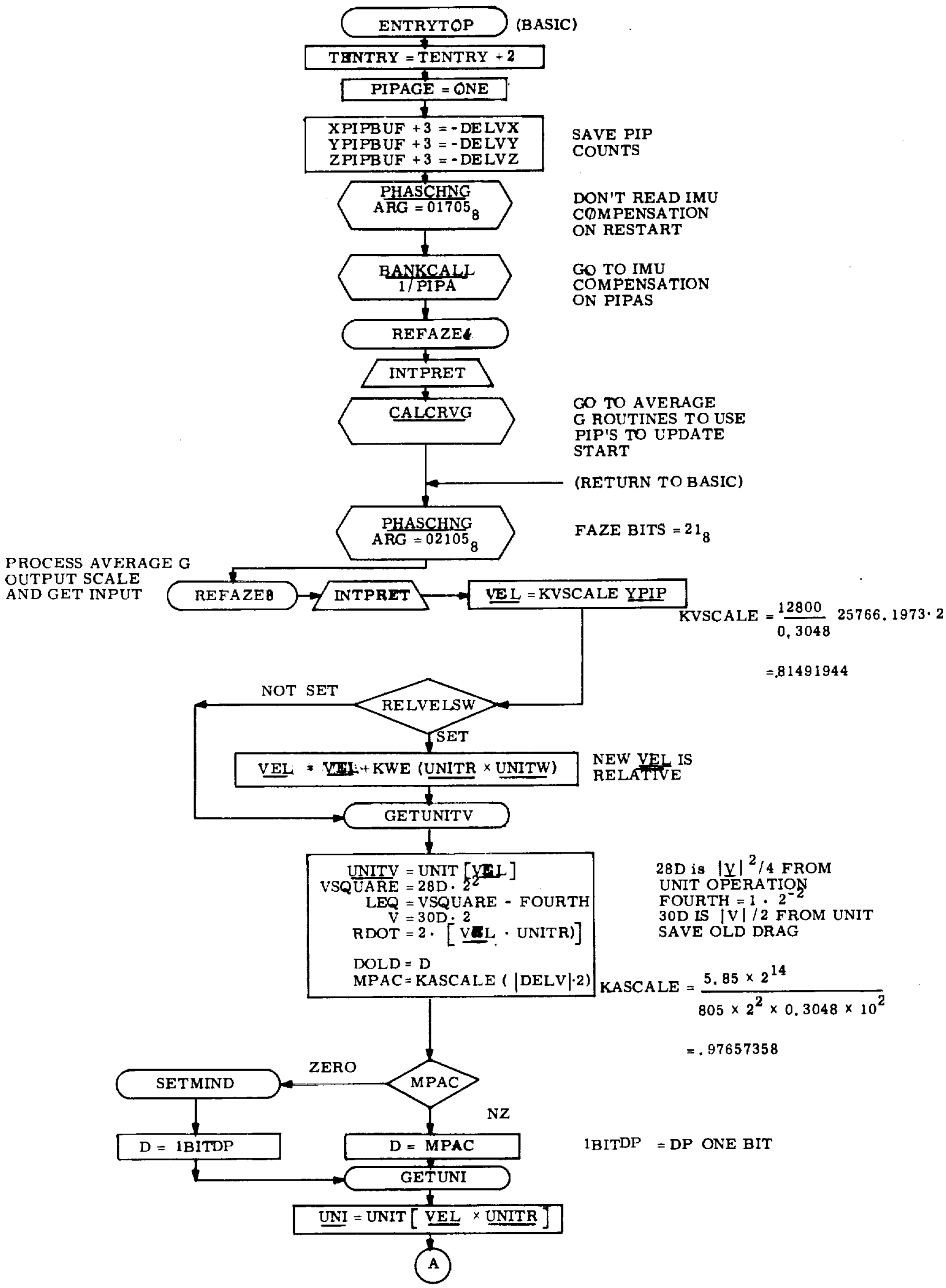
REQUIRES: DTEAROT at 2^{28} CS.

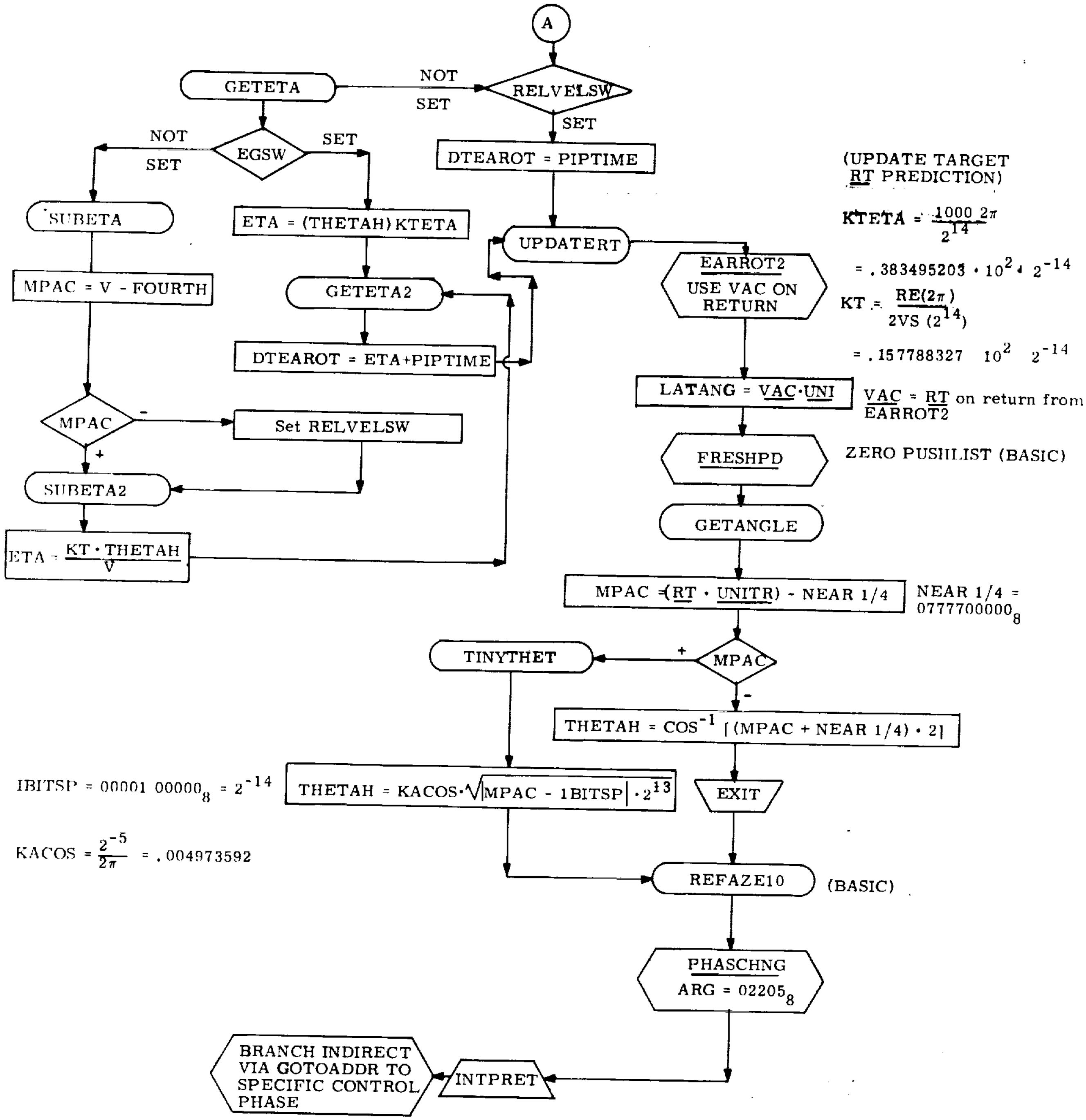
RESULTS: LEAVES RESOLVED VECTORS IN RT WITH EASTERLY AND NORMAL COMPONENTS IN RTEAST AND RTNORM at THE SAME SCALING.

FOR CONTINUOUS UPDATE, ONLY ONE ENTRY TO EARROT1 IS REQUIRED, WITH SUBSEQUENT ENTRIES AT EARROT2.



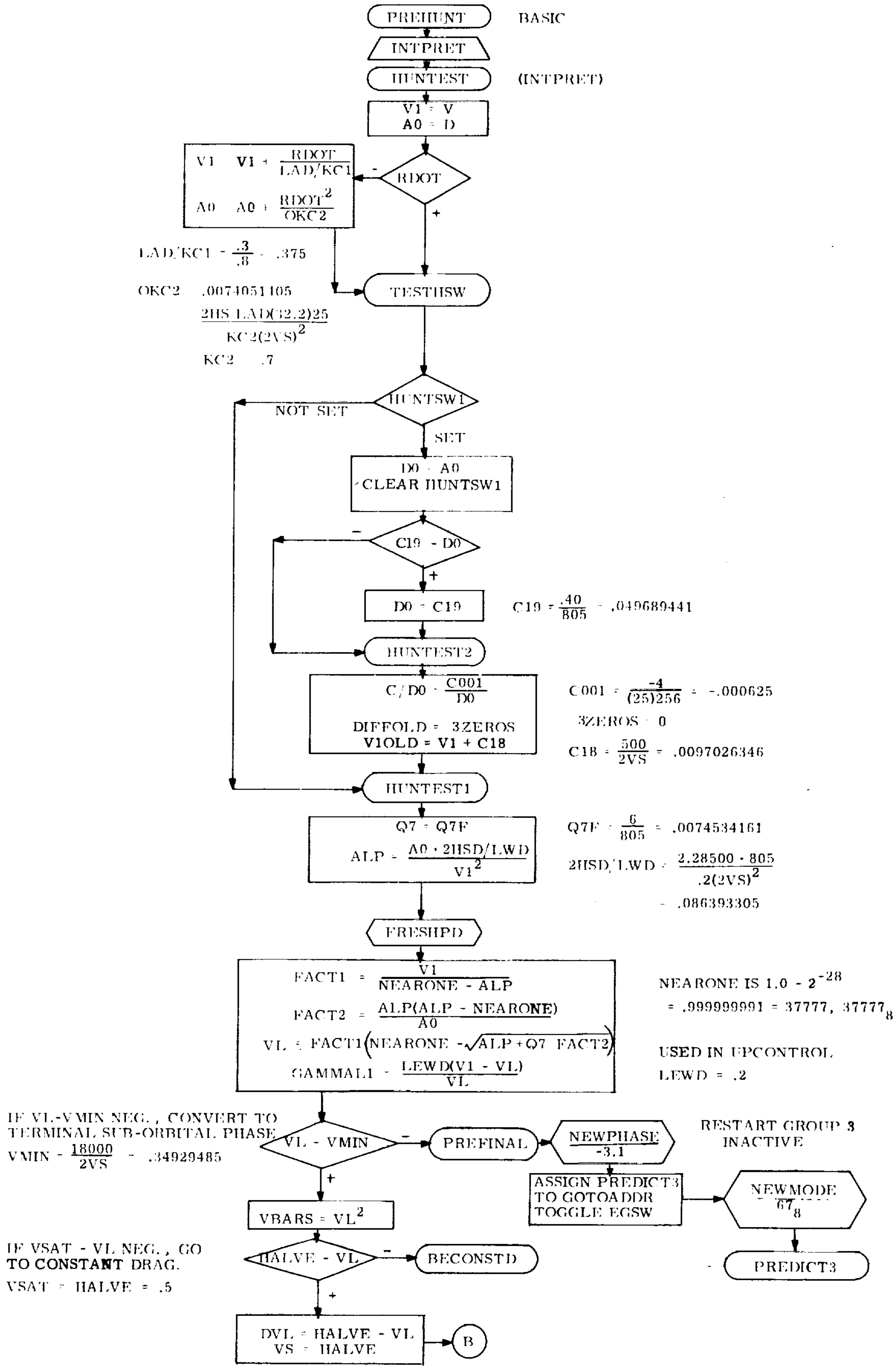
PROCESS PIPA READING TO UPDATE STATE

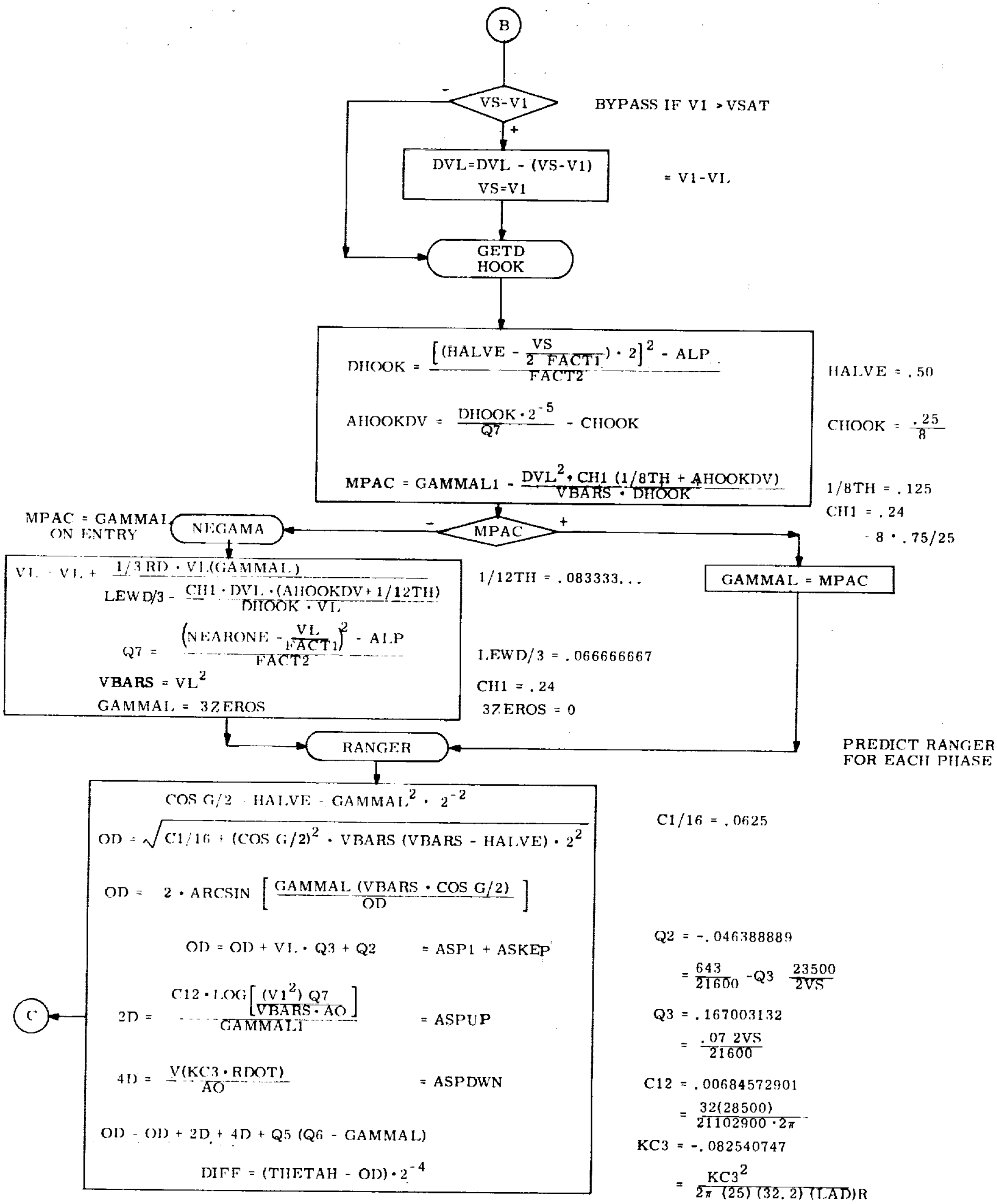




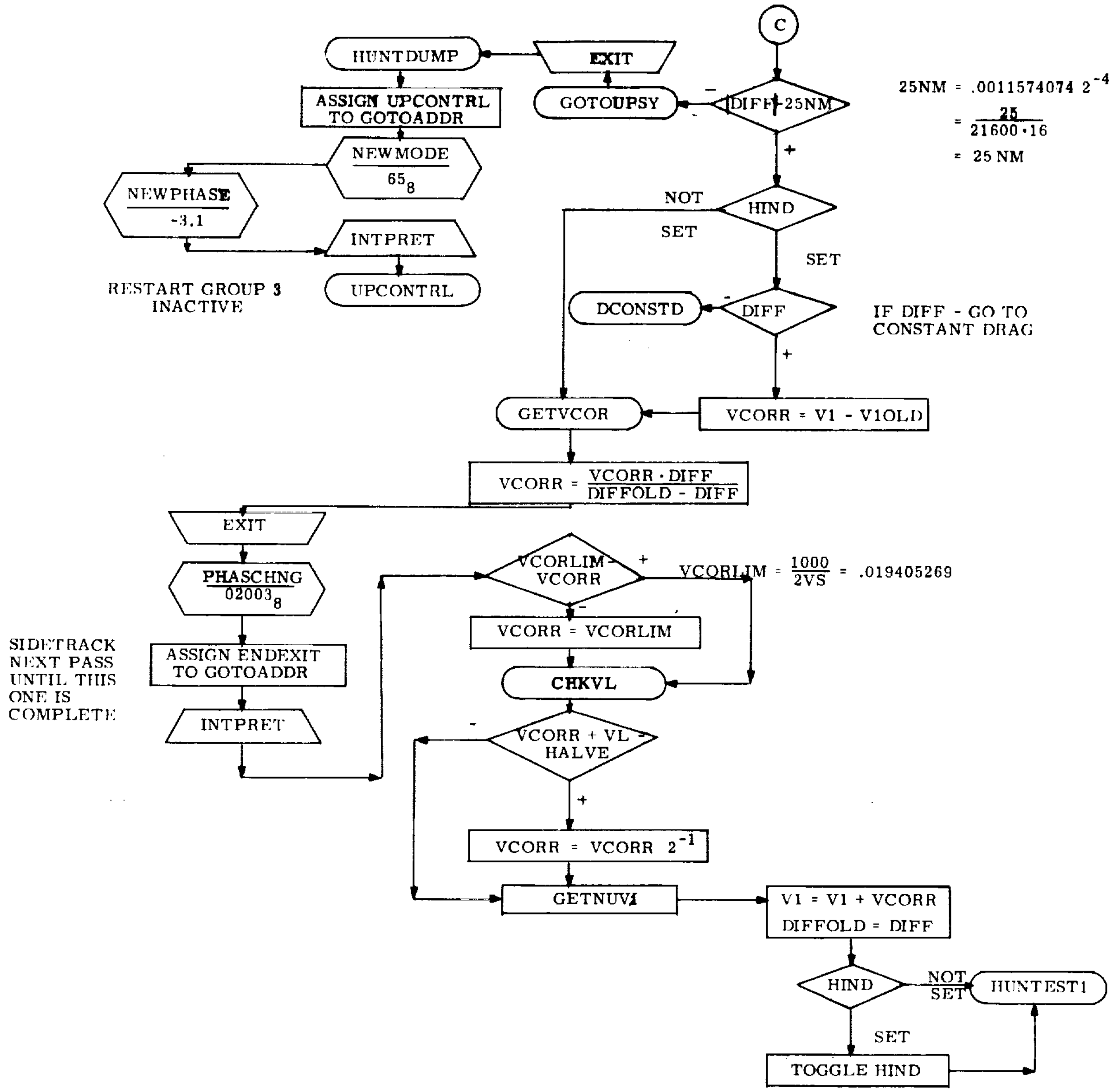
NOTE: ABOVE BRANCH IS TO ROLL - CONTROL ROUTINE APPROPRIATE TO CURRENT PHASE. FOLLOWING SECTIONS DESCRIBE THE APPROPRIATE ROUTINES.

HUNTEST: CHECK TO SEE IF PREDICTED RANGE AT NOMINAL L/D FROM PRESENT STATE IS LESS THAN DESIRED RANGE. IF NOT - ROLL COMMANDED BY CONSTANT DRAG CONTROLLER; IF SO-SET CONSTANTS INTO ENDHNTST AND SWITCH PHASE TO UPCONTRL.



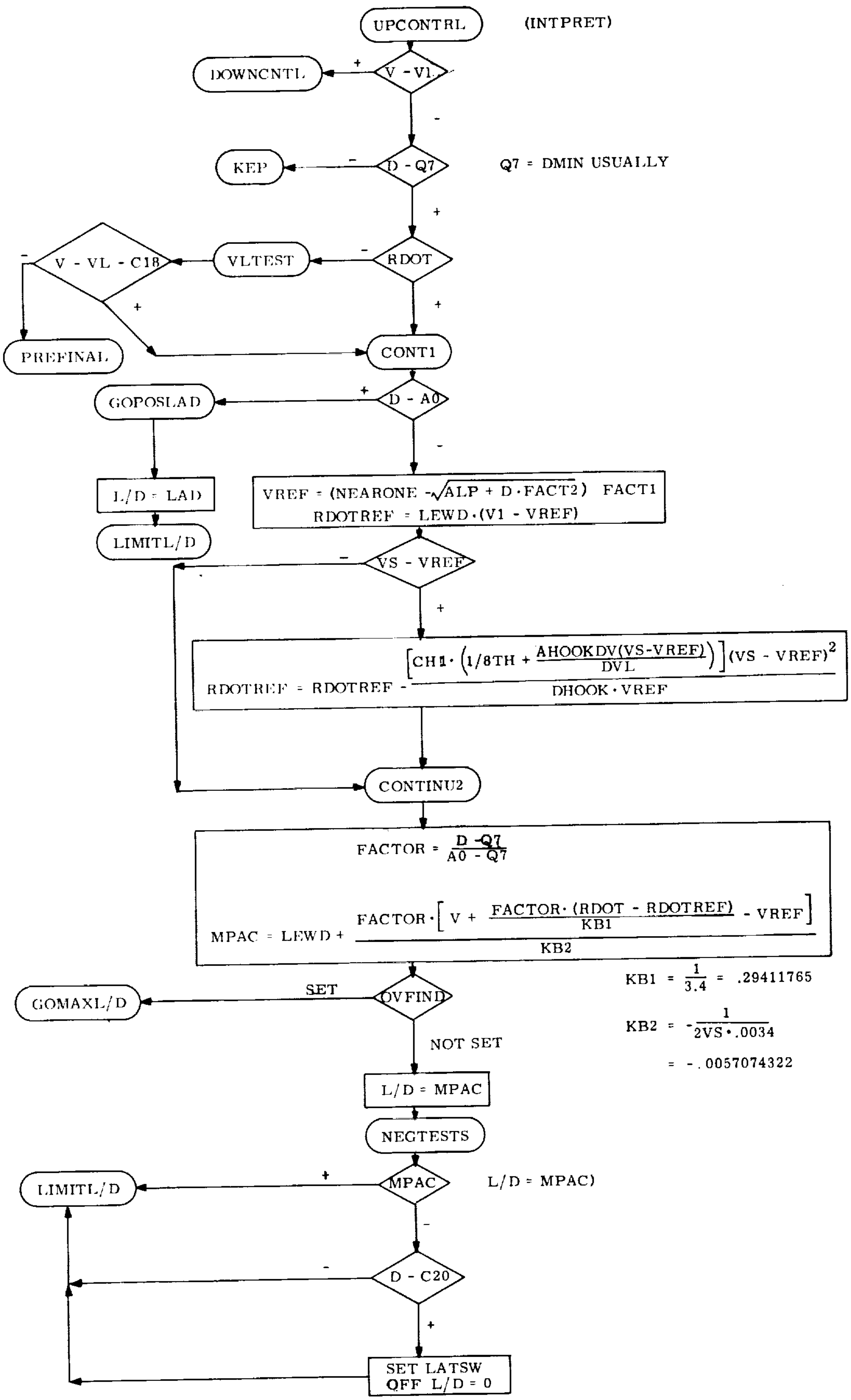


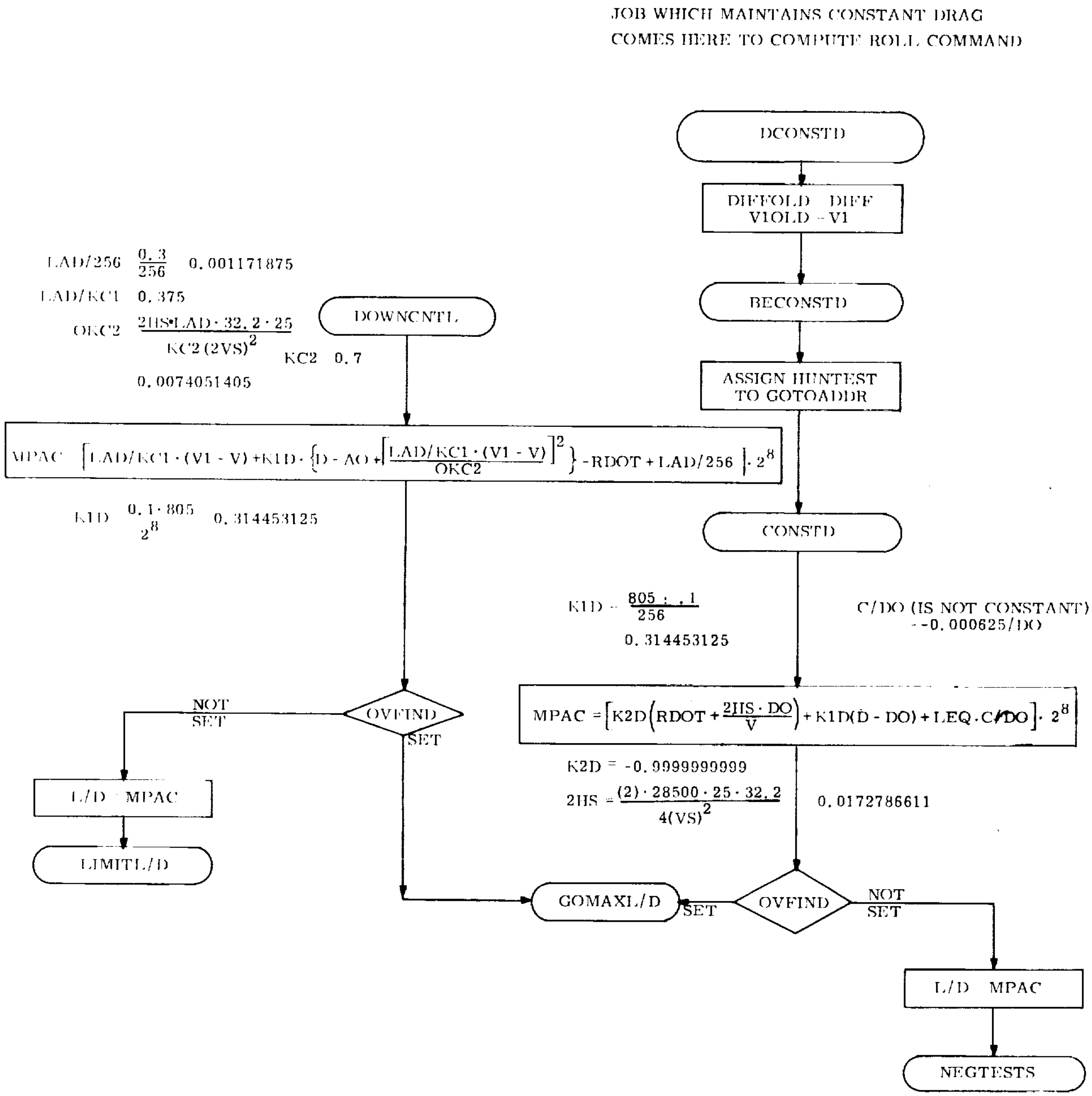
NOTE: Log function yields minus the natural log times 2^{-5}. LOG (ARG) = -2^{-5} ln (ARG)

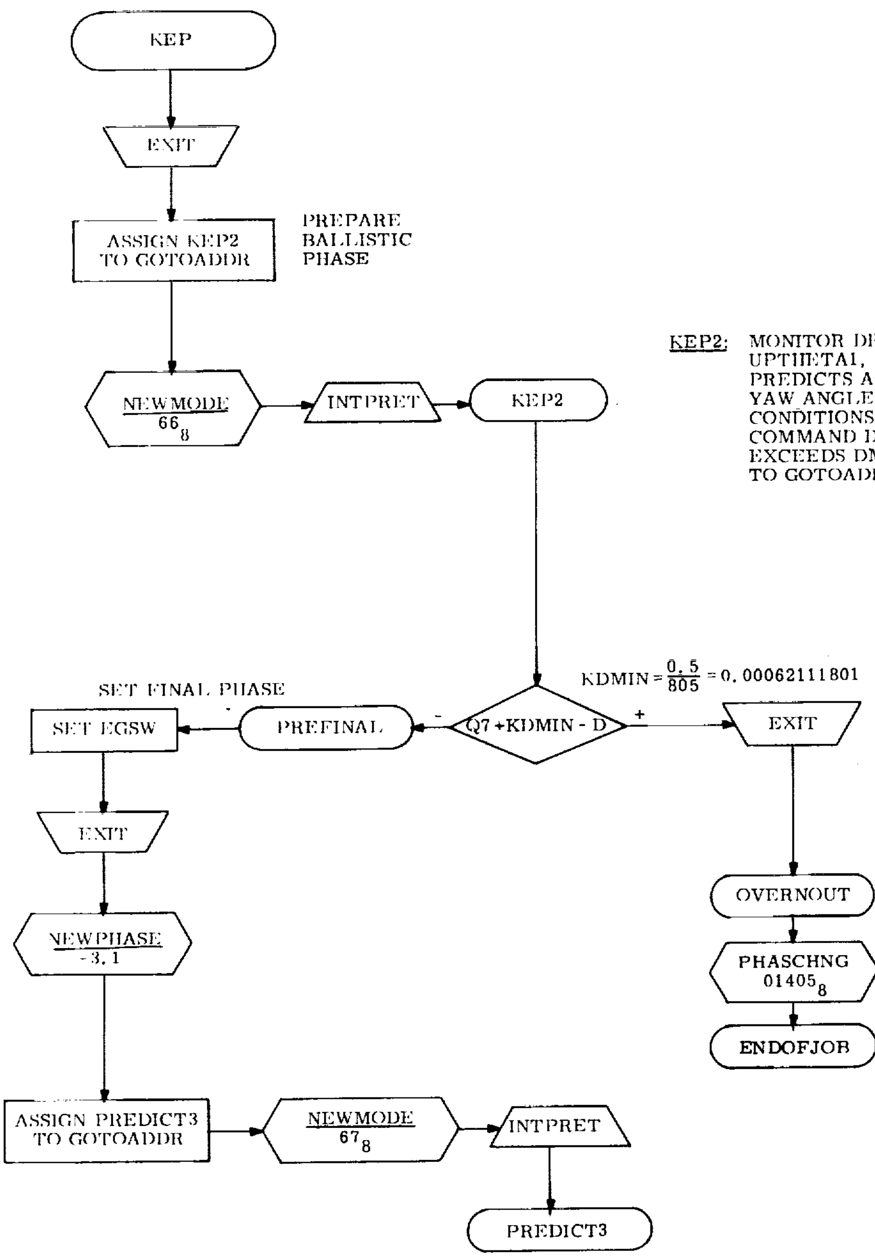


C
HUNTDUMP
EXIT
ASSIGN UPCONTRL TO GOTOADDR
GOTOUPSY
DIFF - 25NM
25NM = .0011574074 2^-4
= 25 / 21600·16
= 25 NM
NEWMODE 65₈
NEWPHASE -3.1
NOT SET
HIND
SET
INTPRET
UPCONTRL
RESTART GROUP 3 INACTIVE
DCONSTD
DIFF
IF DIFF - GO TO CONSTANT DRAG
GETVCOR
VCORR = V1 - V1OLD
VCORR = VCORR · DIFF / DIFFOLD - DIFF
EXIT
PHASCHNG 02003₈
VCORLIM - VCORR
VCORLIM = 1000 / 2VS = .019405269
VCORR = VCORLIM
SIDETRACK NEXT PASS UNTIL THIS ONE IS COMPLETE
ASSIGN ENDEXIT TO GOTOADDR
CHKVL
INTPRET
VCORR + VL - HALVE
VCORR = VCORR 2^-1
GETNUV1
V1 = V1 + VCORR
DIFFOLD = DIFF
HIND
NOT SET
HUNTEST1
SET
TOGGLE HIND

UPCONTROL: CONTROLS ROLL DURING SUPER-CIRCULAR PHASE; THIS SETTING CAUSES CONTROL DRAG JOB STARTKD TO BE TERMINATED. UPCONTROL IS TERMINATED EITHER (1) WHEN DRAG (PIPAS) FALLS BELOW DMIN, OR (2) IF RDOT IS NEGATIVE AND REFERENCE VL EXCEEDS V. IN CASE (1), GOTOADDR IS SET TO KEP2. IN CASE (2), GOTOADDR IS SET TO PREDICT3, SKIPPING THE KEPLER PHASE (KEP2).

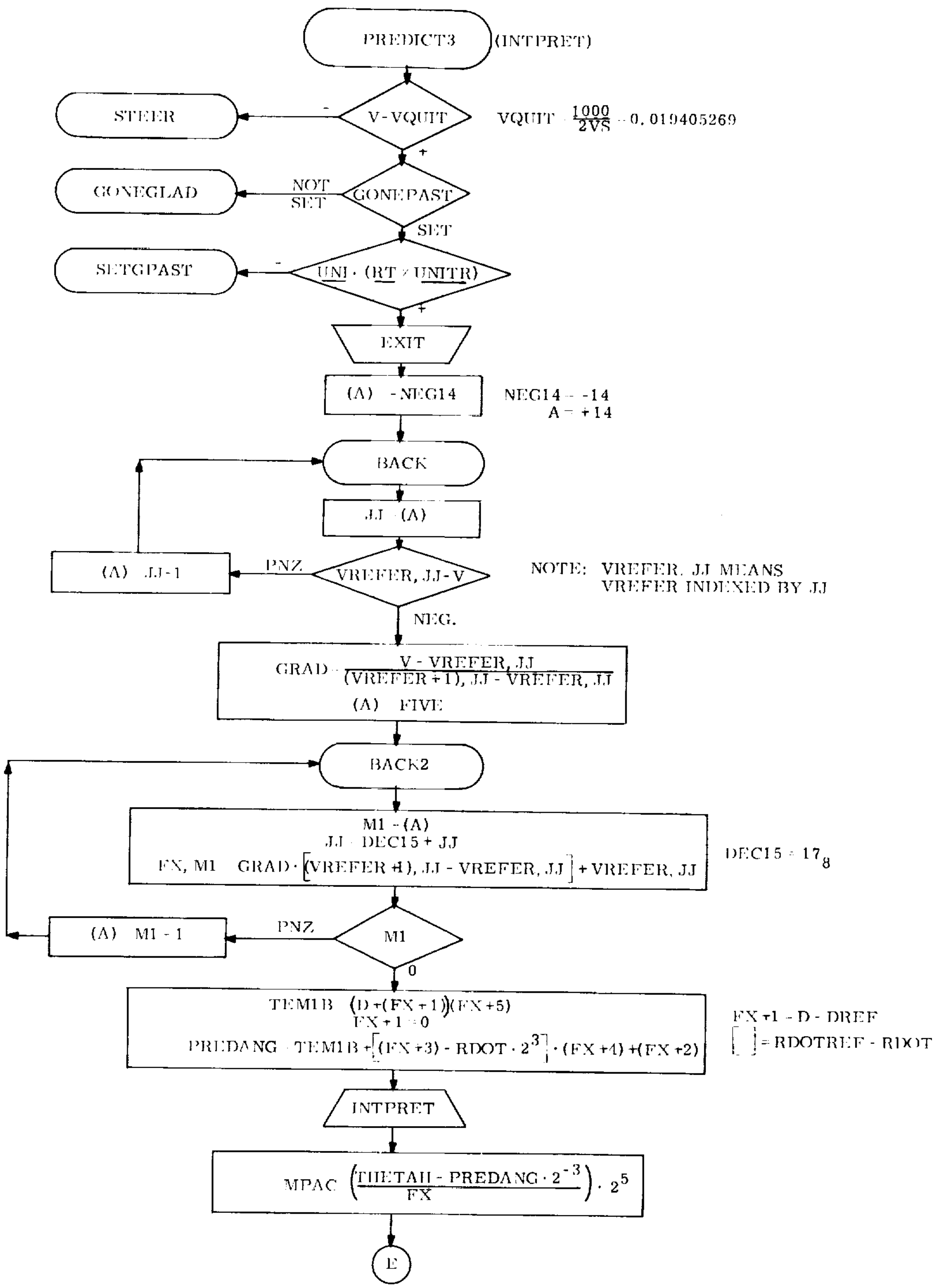



JOB WHICH MAINTAINS CONSTANT DRAG
COMES HERE TO COMPUTE ROLL COMMAND
DCONSTD
DIFFOLD DIFF
V1OLD V1
BECONSTD
ASSIGN HUNTEST
TO GOTOADDR
LAD/256 $\frac{0.3}{256}$ 0.001171875
LAD/KC1 0.375
OKC2 $\frac{2HS \cdot LAD \cdot 32.2 \cdot 25}{KC2\,(2VS)^2}$
KC2 0.7
0.0074051405
DOWNCNTL
MPAC $\left[LAD/KC1 \cdot (V1 - V) + K1D \cdot \left\{D - AO + \left[\frac{LAD/KC1 \cdot (V1 - V)}{OKC2}\right]^2\right\} - RDOT + LAD/256\right] \cdot 2^8$
K1D $\frac{0.1 \cdot 805}{2^8}$ 0.314453125
CONSTD
K1D = $\frac{805 \cdot .1}{256}$
0.314453125
C/DO (IS NOT CONSTANT)
= -0.000625/DO
MPAC = $\left[K2D\left(RDOT + \frac{2HS \cdot DO}{V}\right) + K1D(\dot{D} - DO) + LEQ \cdot C/DO\right] \cdot 2^8$
K2D = -0.9999999999
2HS = $\frac{(2) \cdot 28500 \cdot 25 \cdot 32.2}{4(VS)^2}$
0.0172786611
OVFIND
NOT SET
SET
L/D MPAC
LIMITL/D
GOMAXL/D
OVFIND
SET
NOT SET
L/D MPAC
NEGTESTS

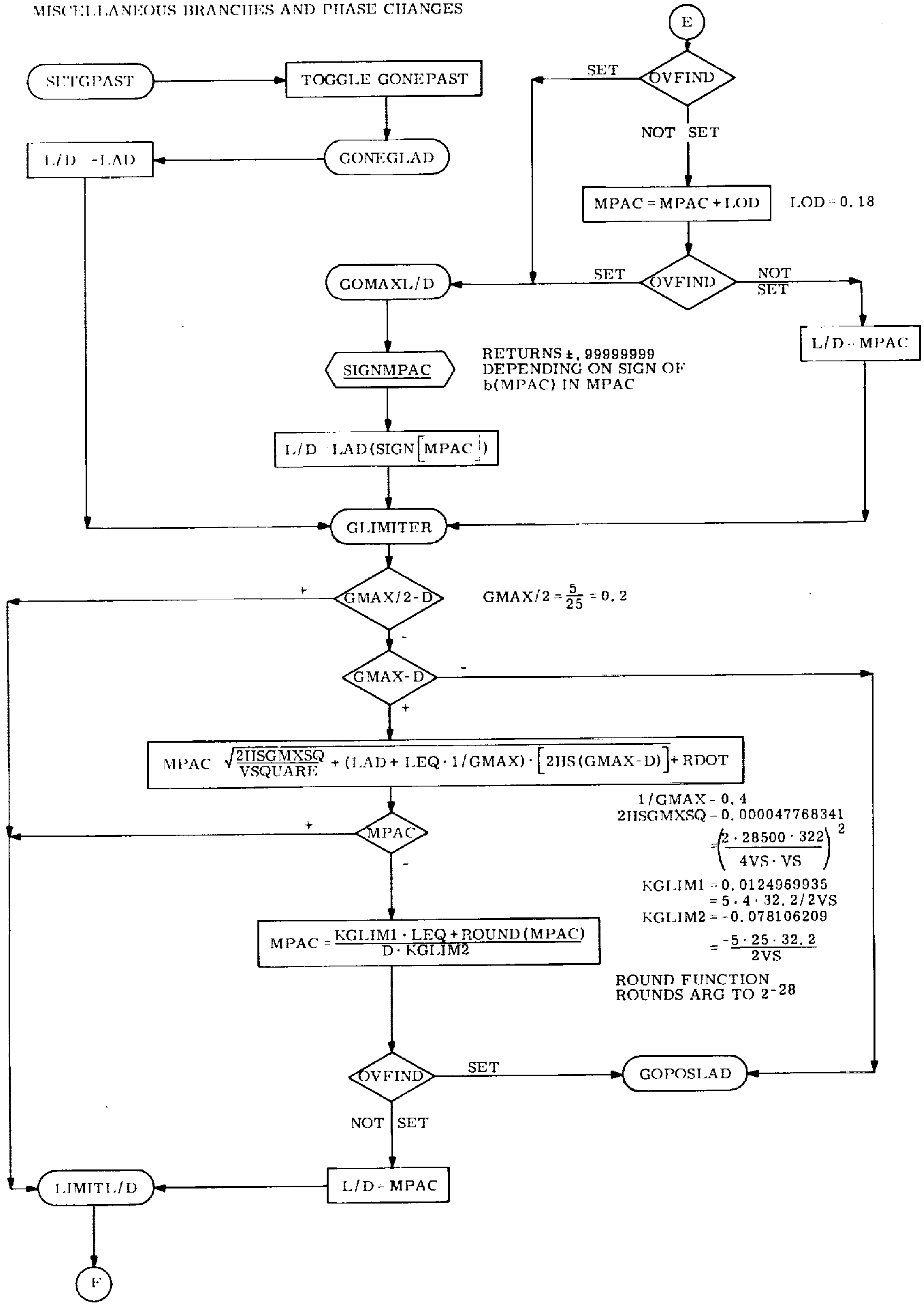


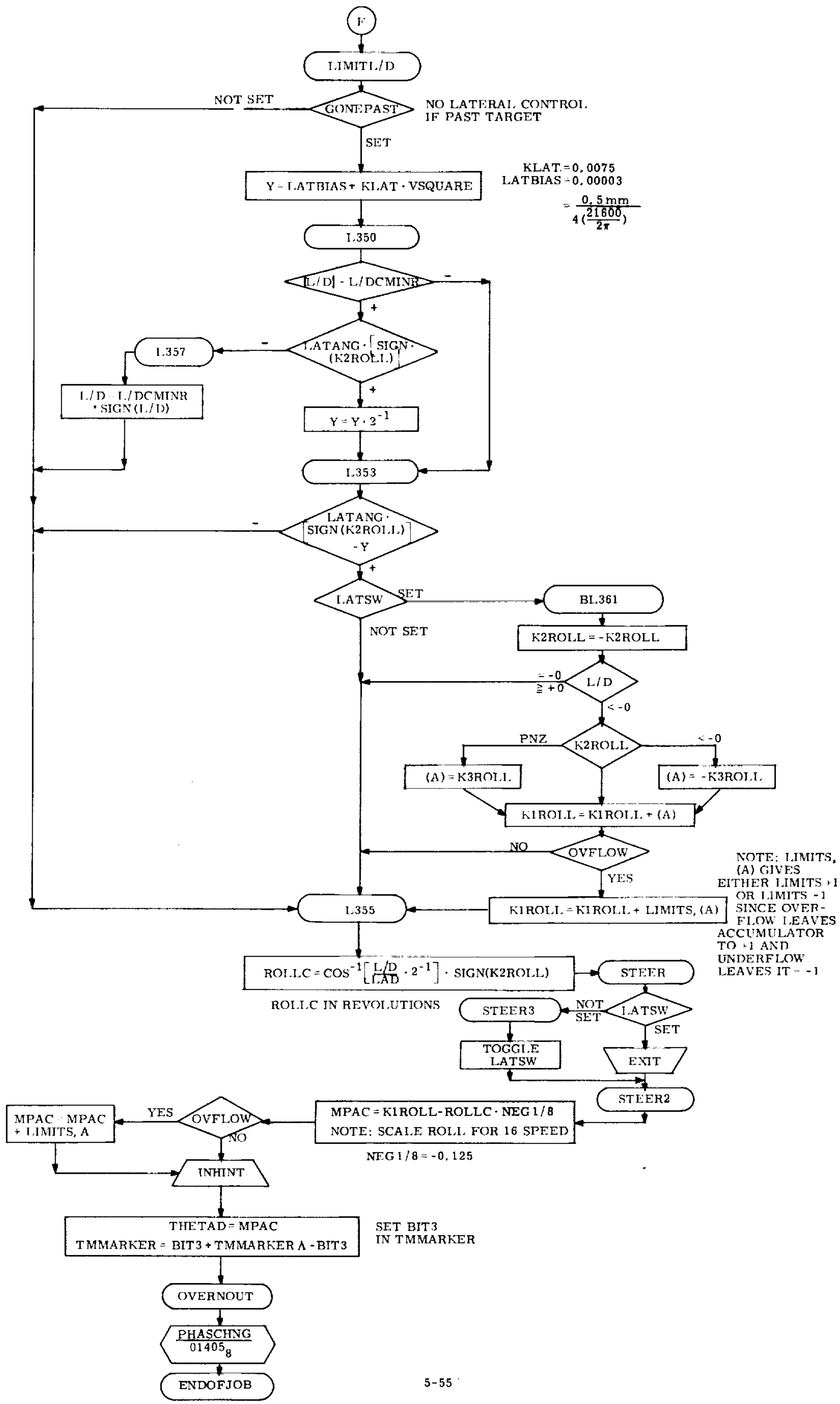
KEP2: MONITOR DRAG DURING KEPLER PHASE. UPTHETA1, A SEPARATE JOB, MEANWHILE PREDICTS AND COMMANDS PITCH AND YAW ANGLES FOR SECOND ENTRY CONDITIONS THERE IS NO CHANGE IN ROLL COMMAND DURING KEP2. WHEN DRAG EXCEEDS DMIN2, PREDICT3 IS ASSIGNED TO GOTOADDR.

PREDICT3: CONTROLS FINAL SUB-ORBITAL PHASE.

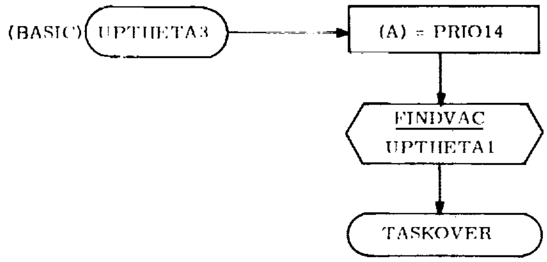


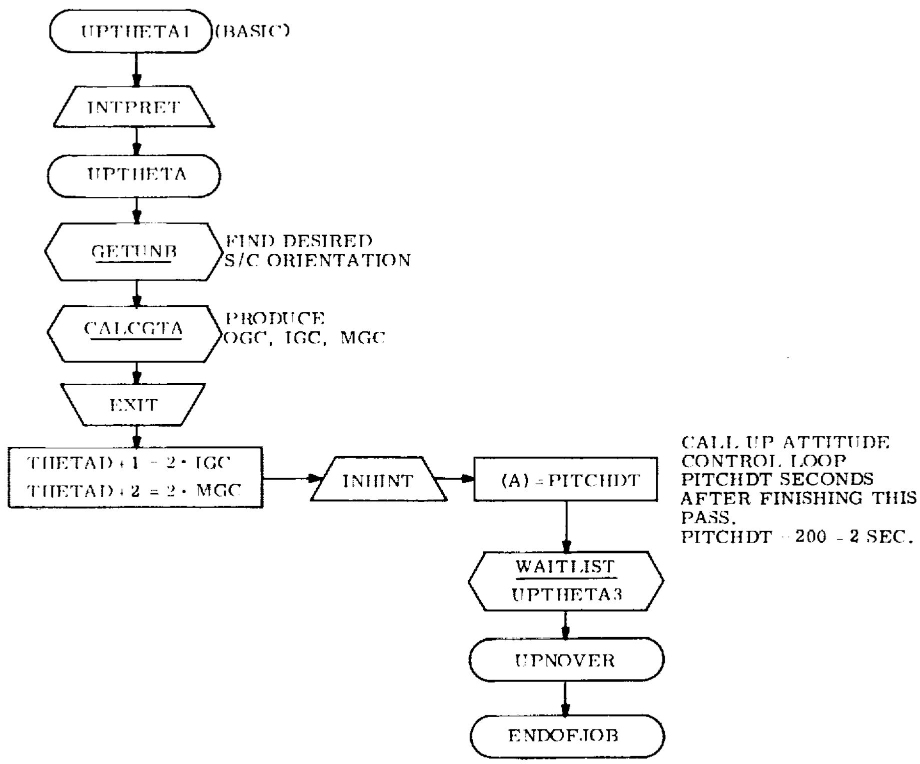
MISCELLANEOUS BRANCHES AND PHASE CHANGES




F
LIMITL/D
NOT SET
GONEPAST
NO LATERAL CONTROL IF PAST TARGET
SET
Y = LATBIAS + KLAT · VSQUARE
KLAT = 0.0075
LATBIAS = 0.00003
= 0.5 mm / 4 (21600/2π)
L350
|L/D| - L/DCMINR
-
+
L357
LATANG · [SIGN · (K2ROLL)]
L/D = L/DCMINR · SIGN (L/D)
Y = Y · 2^-1
L353
LATANG · [SIGN (K2ROLL)] - Y
LATSW
SET
NOT SET
BL361
K2ROLL = -K2ROLL
L/D
= -0
≧ +0
< -0
K2ROLL
PNZ
< -0
(A) = K3ROLL
(A) = -K3ROLL
K1ROLL = K1ROLL + (A)
NO
OVFLOW
YES
NOTE: LIMITS, (A) GIVES EITHER LIMITS +1 OR LIMITS -1 SINCE OVERFLOW LEAVES ACCUMULATOR TO +1 AND UNDERFLOW LEAVES IT = -1
L355
K1ROLL = K1ROLL + LIMITS, (A)
ROLLC = COS^-1 [L/D / LAD · 2^-1] · SIGN(K2ROLL)
ROLLC IN REVOLUTIONS
STEER
STEER3
NOT SET
LATSW
SET
TOGGLE LATSW
EXIT
STEER2
MPAC = MPAC + LIMITS, A
YES
OVFLOW
NO
MPAC = K1ROLL-ROLLC · NEG 1/8
NOTE: SCALE ROLL FOR 16 SPEED
NEG 1/8 = -0.125
INHINT
THETAD = MPAC
TMMARKER = BIT3 + TMMARKER Λ -BIT3
SET BIT3 IN TMMARKER
OVERNOUT
PHASCHNG
01405₈
ENDOFJOB

ROUTINE TO PREDICT AND SET PITCH AND YAW ANGLES FOR VEHICLE TRIM CONDITIONS.



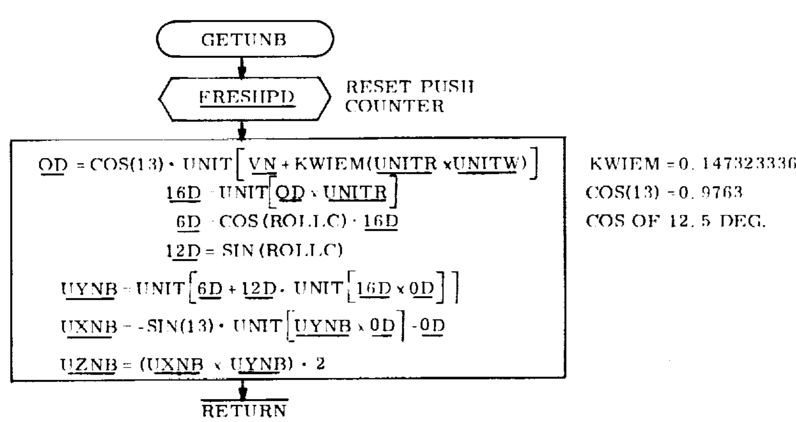


GETUNB

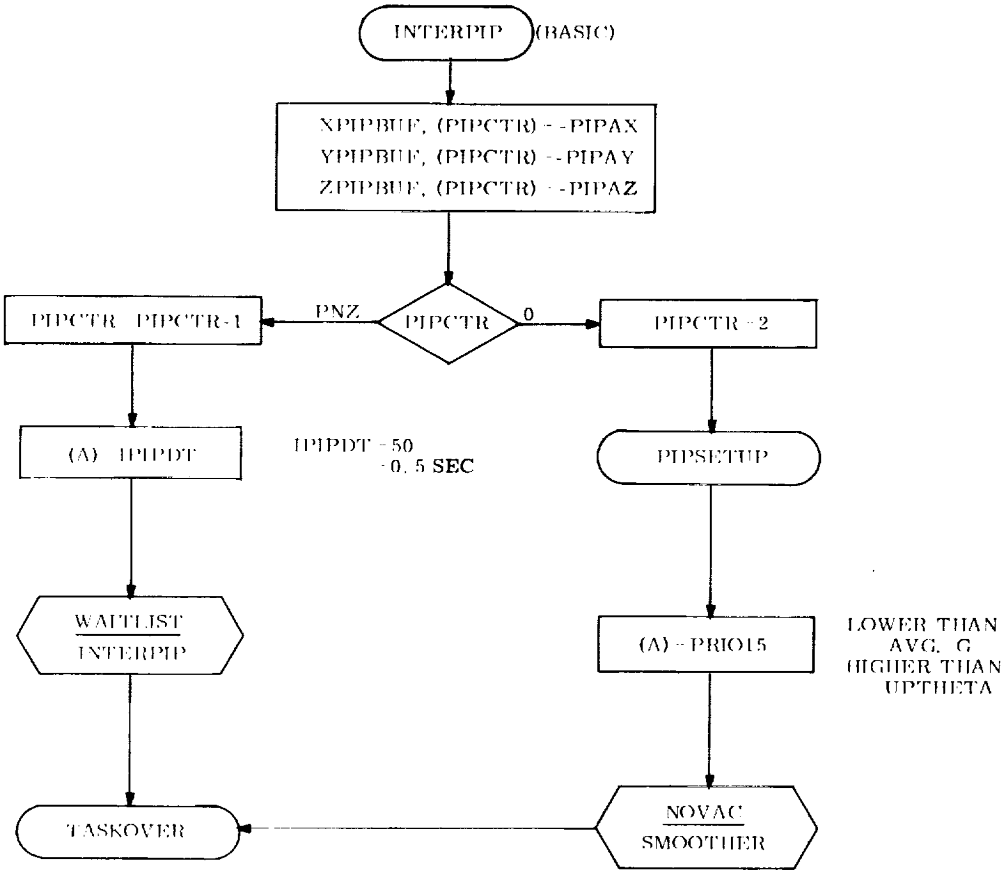
CLOSED SUBROUTINE TO COMPUTE DESIRED NAV BASE ORIENTATION DURING RE-ENTRY.

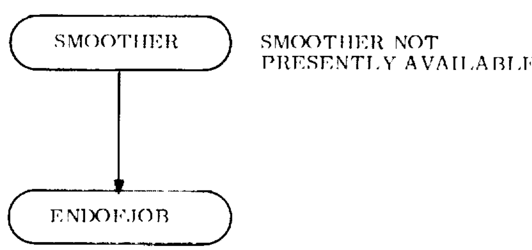
REQUIRES: VN, UNITR, UNITW, AND ROLLC

PRODUCES: UXNB, UYNB, AND UZNB (NAV BASE UNIT VECTORS)

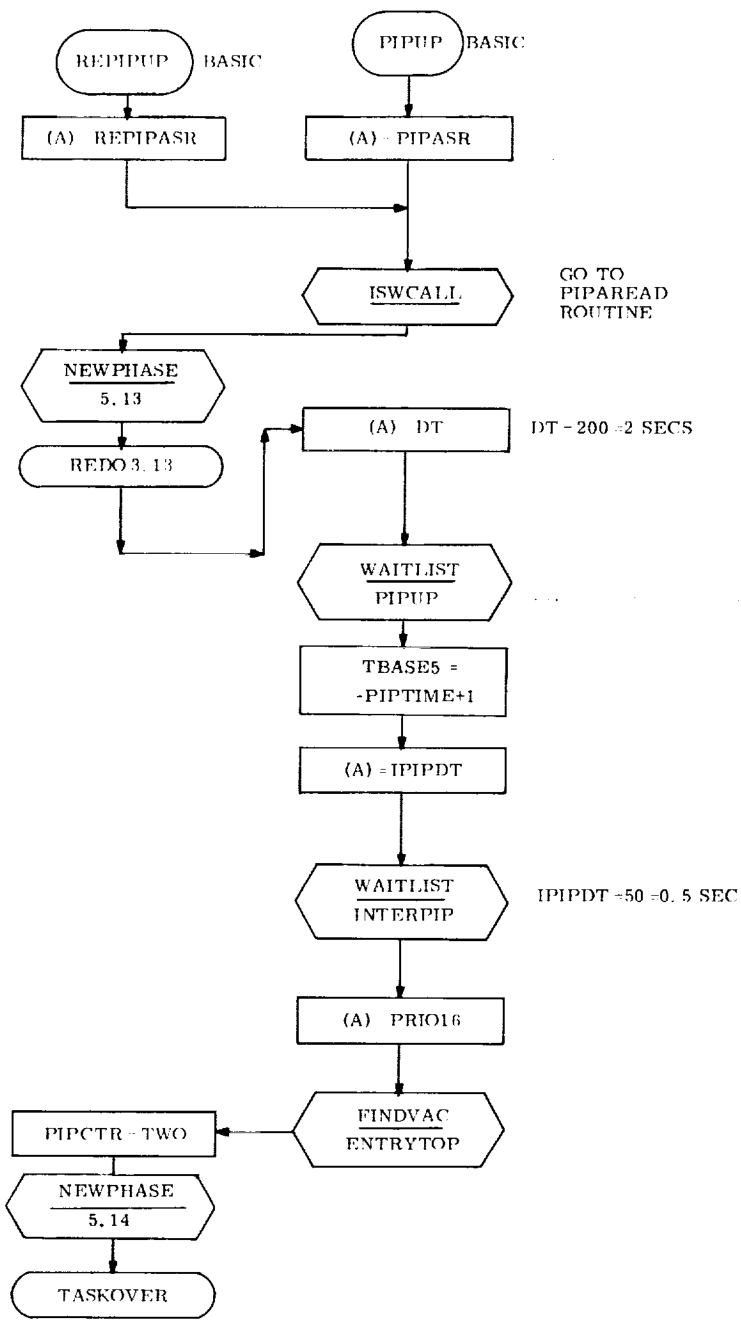


MINOR CYCLE PIP READ JOB

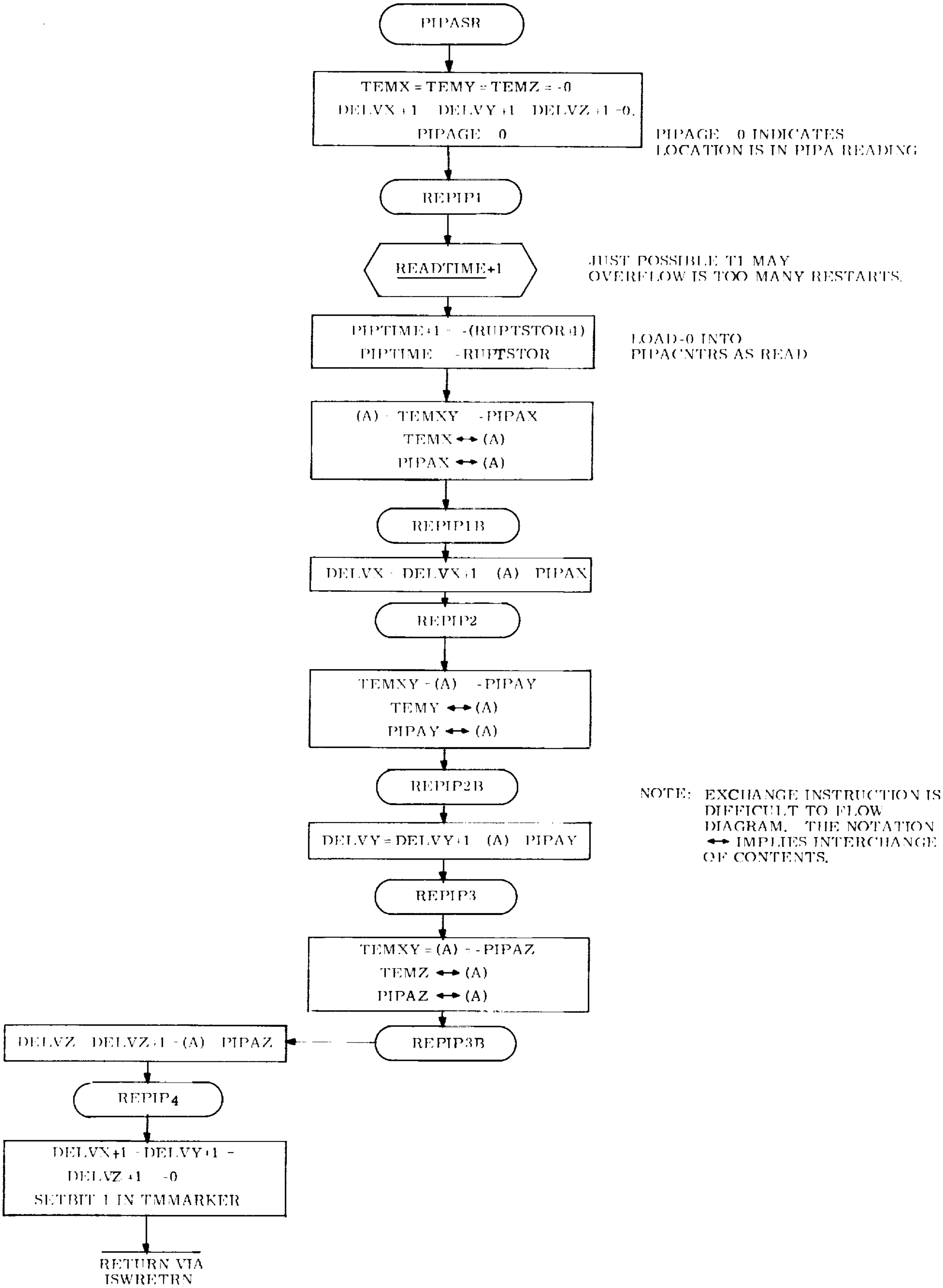




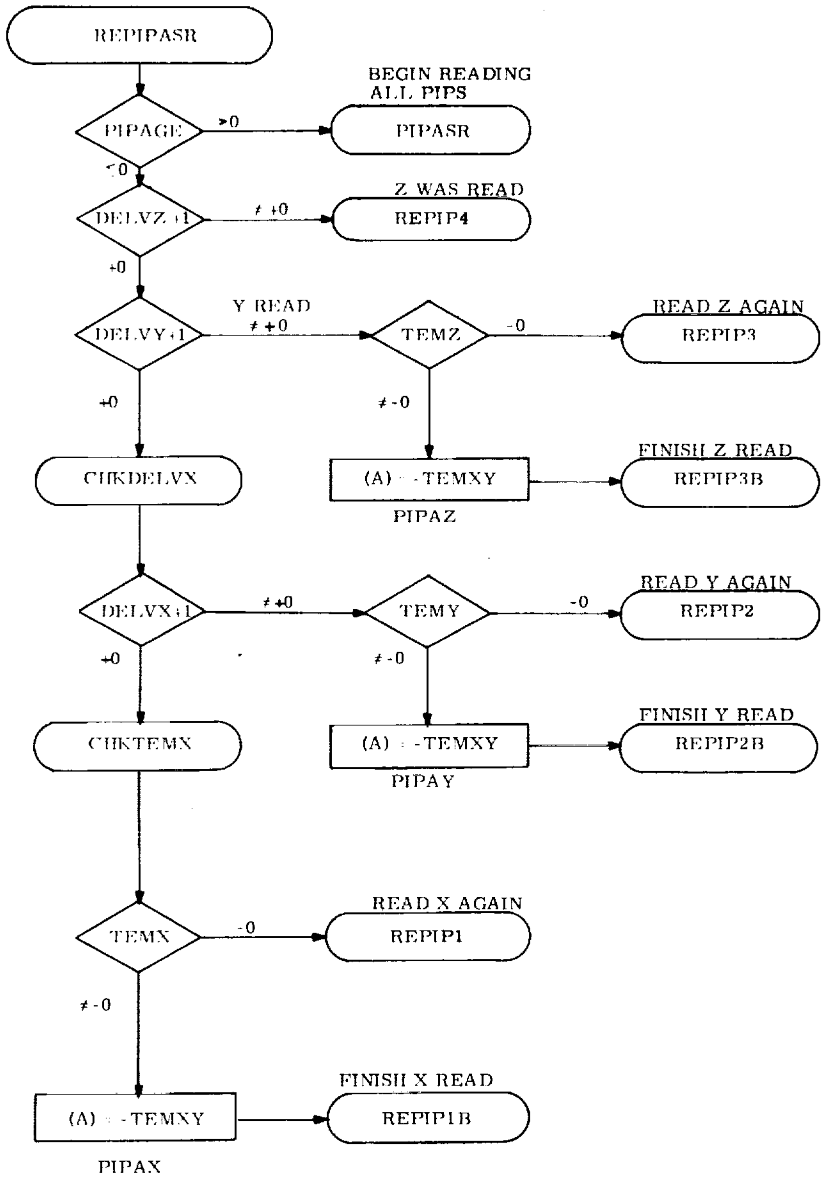
PIPUP - SECTION IS A TASK WHICH READS PIPAS EVERY 2 SECS.



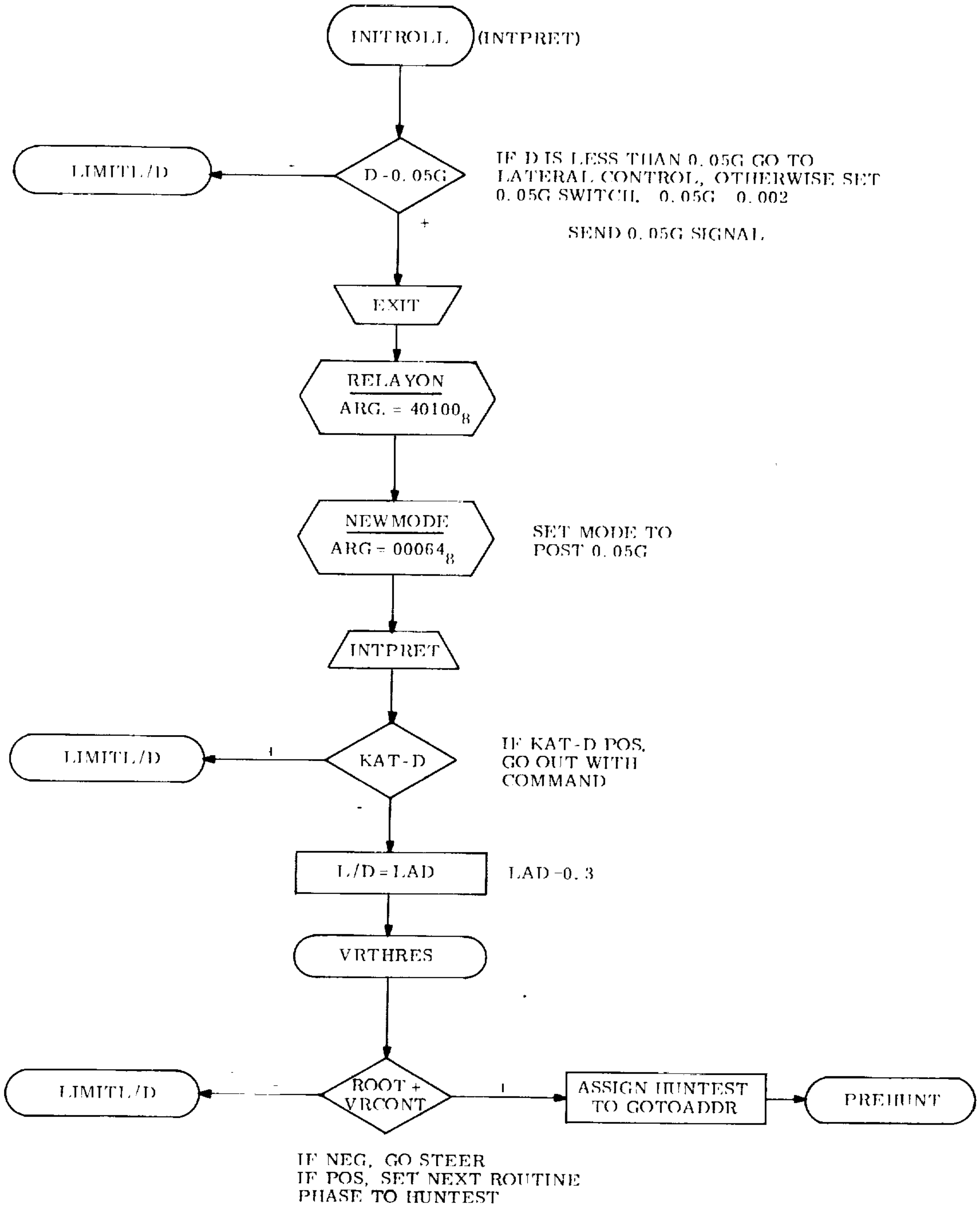
SUBROUTINE TO READ PIPA COUNTERS, SUCH THAT IT BE RESTARTABLE
REQUIRES: ARRIVAL IN INTERRUPTED OR INHIBIT STATE.

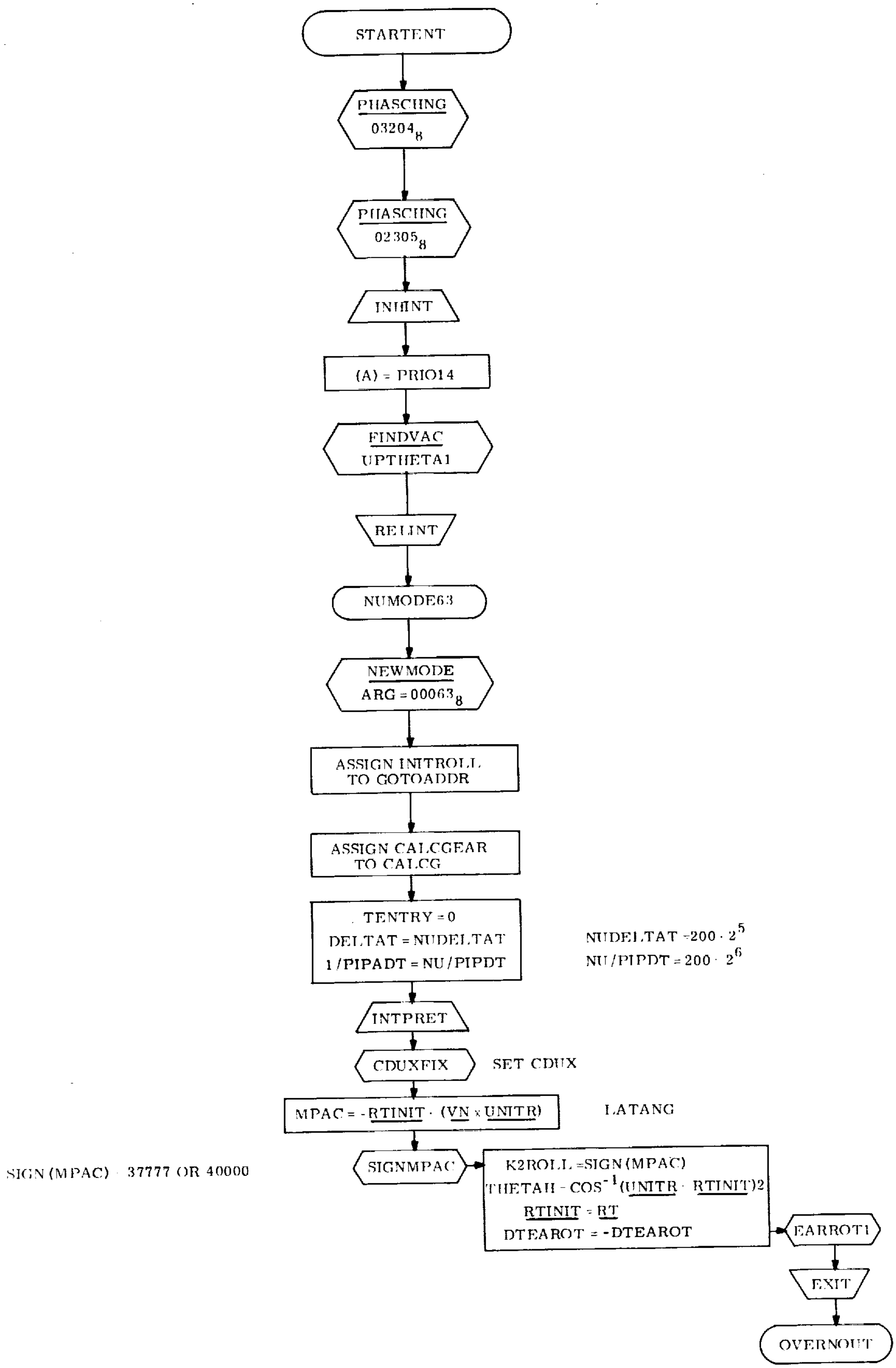


ROUTINE TO RESTART IF READING PIPA COUNTERS



INITROLL - MAINTAINS INITIAL ROLL UNTIL D = KAT AND PASSED INTO HUNTEST (SEE BELOW) WHEN RDOT EXCEEDS VRCONT = 0.0135836886 = 700/2 VSAT





STARTENT
PHASCHNG
03204_8
PHASCHNG
02305_8
INHINT
(A) = PRIO14
FINDVAC
UPTHETA1
RELINT
NUMODE63
NEWMODE
ARG = 00063_8
ASSIGN INITROLL
TO GOTOADDR
ASSIGN CALCGEAR
TO CALCG
TENTRY = 0
DELTAT = NUDELTAT
1/PIPADT = NU/PIPDT
NUDELTAT = 200 · 2^5
NU/PIPDT = 200 · 2^6
INTPRET
CDUXFIX
SET CDUX
MPAC = -RTINIT · (VN × UNITR)
LATANG
SIGN (MPAC) 37777 OR 40000
SIGNMPAC
K2ROLL = SIGN (MPAC)
THETAH = $\cos^{-1}$(UNITR · RTINIT)2
RTINIT = RT
DTEAROT = -DTEAROT
EARROT1
EXIT
OVERNOUT

AVERAGE G INTEGRATOR

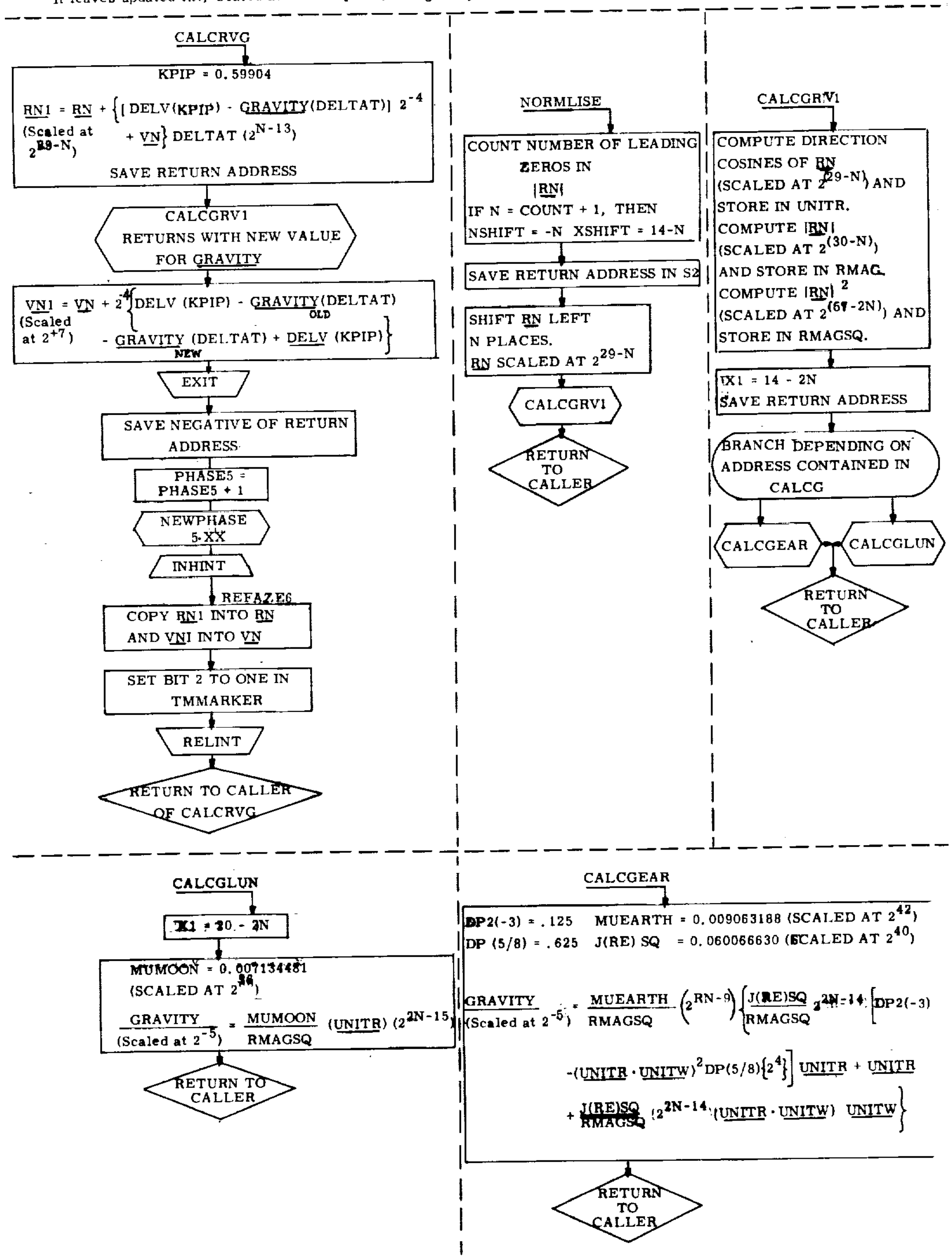
NORMLISE must be called prior to the first entry into CALCRVG. It requires RN scaled to 2^{29} m., and leaves RN normalized, so that the scaled magnitude of the vector contains one leading zero, by shifting the vector left N places.

Routine CALCRVG integrates the equations of motion by averaging the thrust and gravitation accelerations over a time interval DELTAT.

For the earth-centered gravitational field the perturbation due to oblateness is computed to the first harmonic coefficient J.

It requires
1) Thrust acceleration increments in DELV scaled same as PIPAX, Y, Z.
2) VN scaled at 2^7 m/cs.
3) Address of CALCGLUN or CALCGEAR in CALCG.
4) DELTAT scaled at 2^9 cs.
5) Push-down counter set to zero.

It leaves updated RN, scaled at 2^{29-n} m, VN, and gravity scaled at 2^{-5} m/cs/cs.



6. MISSION AND VEHICLE DATA

6.1 Scope

Section 6 is a summary of all Flight 202 mission and vehicle data that have an impact on AGC programming. Data have been collected under the following headings:

Section 6.2 Mission Data. Establishes the outlines of the mission in terms of trajectories, profiles etc. Includes performance figures for Saturn boost phase inasmuch as they affect conditions pertaining at take-over of control by G&N system.

Section 6.3 Memory Data. Contains all mission- and vehicle-dependent data that are, in one form or another, written directly into the memory of the AGC. In a wired-memory computer such as the AGC, the very limited erasable section is intended primarily for storage of computational variables. An attempt has been made to consign those mission parameters that do not change during flight to the fixed section of the memory. Some exceptions have had to be made in the case of the Saturn boost polynomials and SPS aim-point criteria, since these will not be available until shortly before the flight.

Section 6.4 Vehicle Data. Contains information that will mainly affect simulations and rope verification and will not, with only one or two exceptions, appear directly in the AGC program.

Section 6.5 Physical Constants. These definitions will be used in AGC programs and verification work.

Numerical data are presented in the most convenient and widely accepted units. The AGC is, however, programmed in the metric set of kilogram, meter, and centisecond (10^{-2} sec). Conversion to other sets of units is done by use of the factors defined in Section 6.5.2.

Points on the surface of the earth are defined in terms of geodetic latitude and longitude referred to the Fischer ellipsoid of 1960, and geocentric radius.

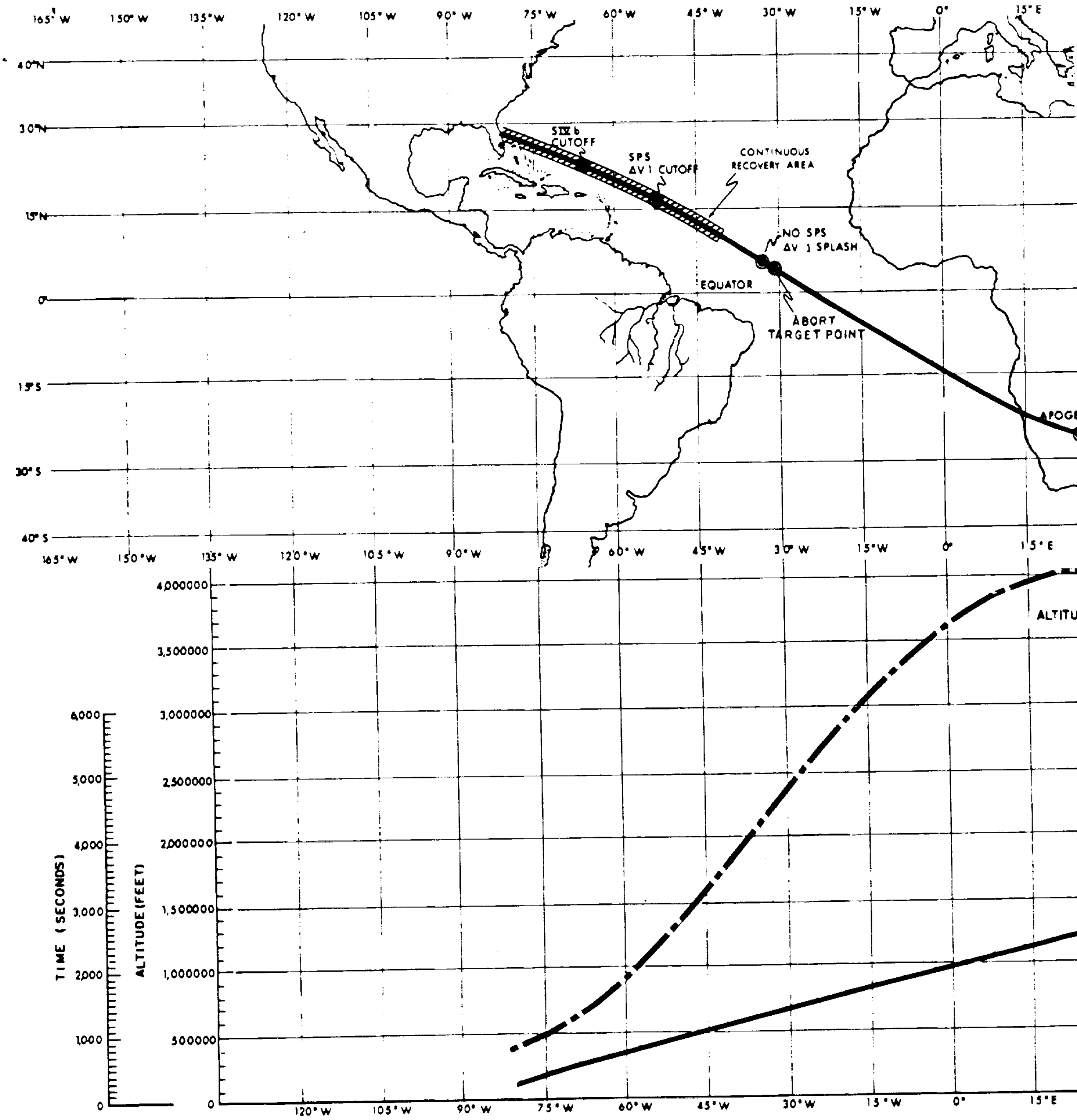
It is pointed out that not all items of numerical data included in this section are to be found in the memory explicitly as defined. They are often rescaled, changed in units, or combined with other data for storage in the most convenient and/or economical fashion.

6.2 Mission Data

6.2.1 Mission Trajectories

Saturn Boost Trajectory[1] (For data from Lift-off to SIVB thrust cut-off)	Apollo Trajectory Document No. 65-FMP-1, Apollo Mission 202, Joint Reference Trajectory, April 12, 1965. Published jointly by MSFC/MSC.
Spacecraft Trajectory (For data from SIVB thrust cut-off to touch down)	Project Apollo Spacecraft Reference Trajectory SA-202 April 9, 1965. Published as MSC Internal Note No. 65-FM-37.
Nominal mission profile	see Fig. 6.1
Major events during nominal mission	see Table 6.1
Nominal Saturn boost profile	see Fig. 6.2

Note 1. MIT is in receipt of a computer print-out of this portion of the referenced trajectory from MSC, which provides additional information at more frequent points during the boost than the document quoted.



S IVB CUTOFF
SPS
ΔV 1 CUTOFF
CONTINUOUS RECOVERY AREA
NO SPS
ΔV 1 SPLASH
EQUATOR
ABORT
TARGET POINT
APOGE
ALTITU
TIME (SECONDS)
ALTITUDE (FEET)

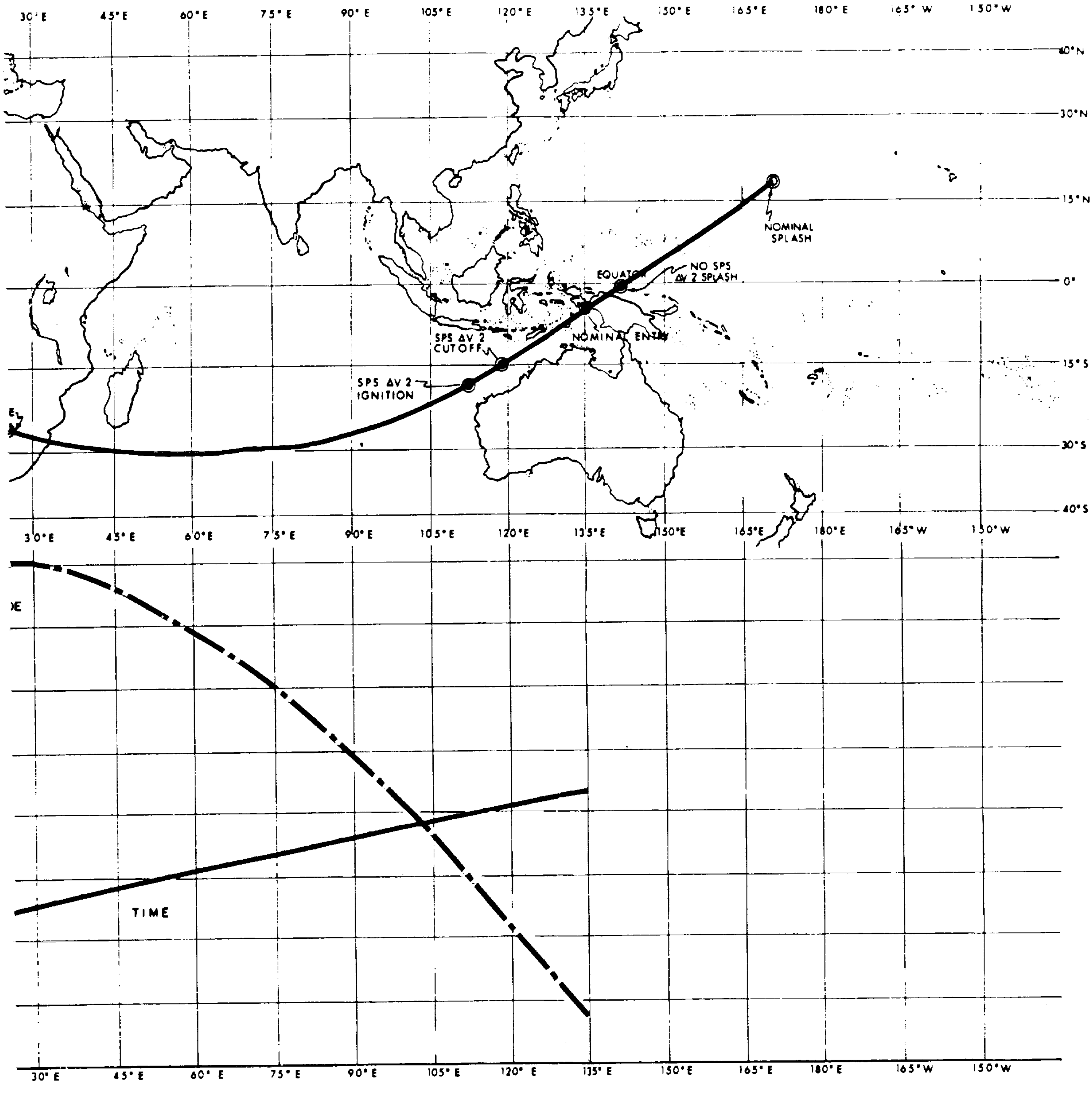


Fig. 6-1 Mission 202 Profile.

Table 6-1

Event	t (sec)	V_i (fps)	γ_i (deg)	AZ_i (deg)	ALT (ft)	N. Geod. Lat. (deg)	W. Long. (deg)	Weight
liftoff	0	1341.61	90	90	0	28.53	80.56	
SIB c/o	148.65	6977.31	62.78	102.34	201,409	28.40	80.00	
SIVB Ign.	151.75	6932.95	63.45	102.37	211,136	28.38	79.96	
LES Jett.	171.75	7097.35	68.46	102.73	269,621	28.31	79.66	
SIVB c/o	609.95	21,802	85.07	111.92	715,530	23.71	65.72	
SPS Ign.	630.95*	21,751	85.52	112.26	752,673	23.24	64.60	43,685
SPS c/o	865.14	25,416	83.76	117.16	1,209,592	17.25	51.70	27,842
Apogee	2395.14	22,440	89.372	110.45	3,995,357	-24.17	-19.81	
Ullage	3998.82							
SPS Ign.	4028.82	25,116	96.28	63.69	1,475,984	-18.55	-112.11	27,801
SPS c/o	4114.82	27,678	97.52	62.17	1,199,135	-15.96	-117.17	21,983
SPS Ign.	4124.82	27,716	97.40	61.99	1,163,191	-15.63	-117.78	21,983
SPS c/o	4127.82	27,818	97.41	61.94	1,152,455	-15.53	-117.97	21,780
SPS Ign.	4137.82	27,855	97.29	61.77	1,116,843	-15.20	-118.58	21,780
SPS c/o	4140.82	27,959	97.30	61.72	1,106,214	-15.10	-118.77	21,577
Entry	4402.0	28,706	93.57	58.65	399,188	-5.11	-134.79	11,000
End of Entry	5262.0	1,483			24,793	17.24	-170.00	

*Data from this time on is from MIT 202 performance simulations

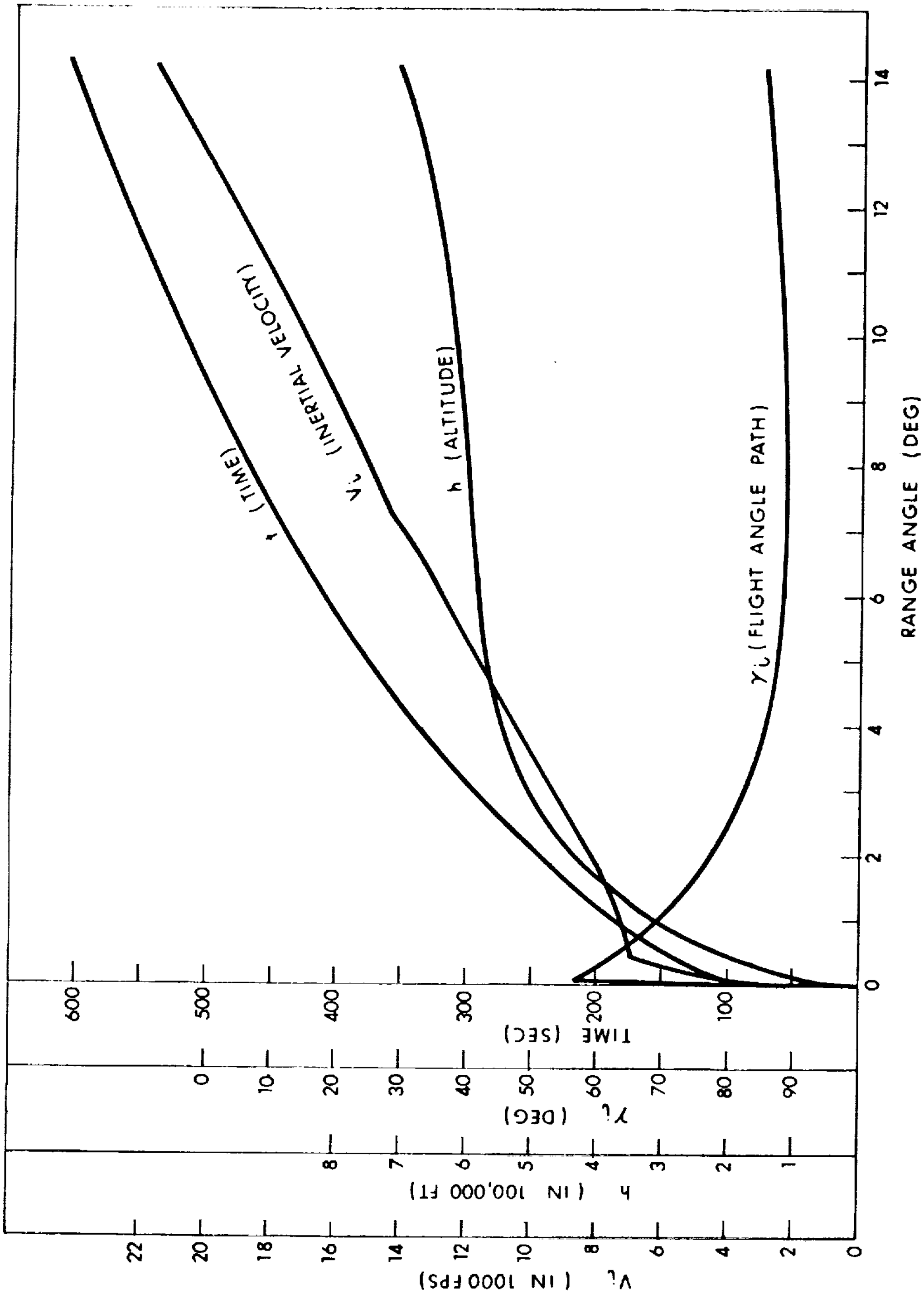


Fig. 6-2 Saturn Boost Trajectory Profile

6.2.2 Nominal SIVB Separation Attitude Conditions

X-axis in plane of maneuver, forward of inertial vertical defined at the launch point by	76.00°
(Y-axis along momentum vector $\underline{R} * \underline{V}$ Z-axis above local horizontal)	
Roll rate	0°/sec
Pitch rate	0°/sec
Yaw rate	0°/sec

6.2.3 3σ Dispersions from Nominal at SIVB Separation

X-axis attitude dispersion	2°
Y-axis attitude dispersion	2°
Z-axis attitude dispersion	2°
Roll rate residual	0.2°/sec
Pitch rate residual	0.2°/sec
Yaw rate residual	0.2°/sec

6.2.4 SIVB Engine-off Transient

Decay time 100%-10%	not available
Decay time 10%-0%	not available
Tail-off impulse 100%-10%	not available
Tail-off impulse 10%-0%	not available

6.3 Memory Data

6.3.1 Prelaunch

	Memory Type	Value
Launch Pad #34: Latitude	E	28.5219 6261°N
Longitude	E	279.4388 587°E
Altitude of G&N above ellipsoid	E	56.9 meters
Inertial reference plane (IMU) azimuth	E	104.9901°E of N at Guidance Reference Release
Optical target 1		
Azimuth	E	Not available
Elevation	E	Not available
Optical target 2		
Azimuth	E	Not available
Elevation	E	Not available
Latitude of local vertical at launch pad	E	28.5231 9792°N

6.3.2 Saturn Boost

		Memory Type	Value
Interval: Lift-off-LET jettison assumed complete		E	171.0 sec
Interval: Lift-off to start of roll maneuver		E	10.0 sec
Interval: Duration of roll maneuver		E	5.0 sec
Interval: Lift-off to start of Pitch maneuver		E	10.0 sec
Interval: Duration of Pitch maneuver		E	126.0 sec
Interval: End of pitch maneuver to LES jetison assumed complete (start of tumble monitor)		E	35.0 sec
Roll maneuver: Rotation about inertial vertical		E	5^{o}
Roll maneuver rate (constant)		E	1^{o}/sec
Pitch polynomial[1] coefficient	A_0	E	$+8.9945\ 6725 \times 10^{1}$
	A_1	E	$+6.0573\ 1859 \times 10^{-4}$
	A_2	E	$-3.3346\ 2947 \times 10^{-3}$
	A_3	E	$-1.8166\ 4060 \times 10^{-4}$
	A_4	E	$+3.1782\ 2761 \times 10^{-6}$
	A_5	E	$-1.8835\ 5082 \times 10^{-8}$
	A_6	E	$+3.9387\ 3259 \times 10^{-11}$

Note 1. Form of pitch polynomial is:

$$\theta = \sum_{n=0}^{6} A_n t^n$$

where θ = angle between inertial horizontal at launch and vehicle X-axis, in degrees

t = Time in secs ($t = 0$ at 10 secs after Lift-off)

6.3.3 Attitude Maneuvers

		Memory Type	Value
Limit:	commanded S/C angular rate:		
	Roll (CSM)	F	7.2°/sec
	Roll (CM only)	F	15°/sec
	Pitch, Yaw (CSM, CM)	F	4°/sec
Interval between attitude updates		F	0.5 sec
Interval for stabilization after maneuver		F	5.0 sec
Interval:	SPS1 cut-off to end of local vertical phase	F	2037.2 sec

[redacted]

6.3.4 TVC (Normal mission)

	Memory Type	Value
CSM c.g. displacement in X-Y plane: (SPS 1)	F	7.37°
CSM c.g. displacement in X-Y plane: (SPS 2)	F	3.37°
CSM c.g. displacement in X-Y plane: (SPS 3)	F	0.57°
CSM c.g. displacement in X-Z plane: (SPS 1)	F	2.51°
CSM c.g. displacement in X-Z plane: (SPS 2)	F	0.53°
CSM c.g. displacement in X-Z plane: (SPS 3)	F	-0.71°
Minimum ΔV criterion for thrust monitor	F	1 ft/s/s
Interval for thrust monitor	F	10 sec
Interval between steering updates	F	2 sec
Steer law gain (K_1)	F	0.125
Steer law integrator loop gain (K_2)	F	0.010
Integrator saturation limit	F	1.0°
Steer law coefficient (C)	F	0.5
Maximum Interval: freeze CDUs to engine-off cmnd.	F	4.0 sec
Interval: SIVB/CSM Sep. - SPS 1 ignition	F	12.7 sec
Interval: SPS 1 cut-off - SPS 2 ignition	E	3163.67 sec
Interval: SPS 2, 3, cut-off - SPS 3, 4 ignition	F	10 sec
Interval: SPS 3, 4 ignition - SPS 3, 4 cut-off	F	3 sec
Interval: + X translation - SPS 2 ignition	F	30 sec
Interval: between SCS mode change commands	F	0.25 sec
Interval: Gimbal mot. power ON - Engine start	F	4.0 sec

[redacted]

Interval: Engine off - Gimbal mot. power OFF (SPS1, 4 Abort)	F	7.0 sec
Interval: Engine off - Gimbal motor power OFF (SPS2)	F	2 sec
Interval: Engine off - ΔV mode OFF (SPS1, 4, Abort)	F	10.5 sec
Interval: Engine off - ΔV mode OFF (Tumble)	F	2.0 sec
Minimum Interval: RVT update to SPS2 ignition	F	50 sec
Maximum Interval: Receipt of SIVB/CSM sep to receipt of uplink abort	F	1.7 sec
Interval: SPS1 cut-off to FDAI align command	F	300 sec
Interval: mean effective SPS tail-off duration	F	0.53 sec
SPS1 aim-point criteria		
Semi-major axis	E	2.249 107 6 x 10^7 feet
Eccentricity	E	0.109 885 56
SPS2 aim-point criteria		
Semi-major axis	E	2.829 095 3 x 10^7 feet
Eccentricity	E	0.253 412 22
Interval: Lift-off - touch down (Nominal mission)	E	5243 sec

6.3.5 Entry (Normal mission)

	Symbol	Memory Type	Value
CSM attitude for SM/CM Separation:			
X-axis above velocity vector by		F	60^{o}
(Y-axis along monentum vector ($\underline{R} * \underline{V}$),			
Z-axis above velocity vector)			
CM Pacific pre-entry attitude:			
X-axis below velocity vector by		F	160^{o}
(Y-axis along momentum vector ($\underline{R} * \underline{V}$),			
Z-axis below velocity vectory. A lift-vector down attitude).			
Trim angle of attack		F	22^{o}
Interval: SM/CM Sep. - start maneuver		F	5 sec
Pacific recovery point: Latitude		E	17.25^{o}N
Longitude		E	170.00^{o}E
Constant drag gain (on drag)	C16	F	0.1
Constant drag gain (on RDOT)	C17	F	0.00497
Lead velocity for up control start	C18	F	500 ft/s
Minimum constant drag	C19	F	40 ft/s/s
Minimum D for lift up	C20	F	175 ft/s/s
Factor in AHOOK computation	CHOOK	F	0.25
Factor in GAMMAL computation	CH1	F	0.75
G-limit	GMAX	F	10g
Minimum drag for lift up if down	KA	F	0.2g
Up control gain, optimized	KB2	F	0.0034
Up control gain, optimized	KB2	F	3.4
Factor in V1 computation	KC1	F	0.8
Factor in A0 computation	KC2	F	0.7
Lateral switch gain	KLAT	F	0.0075
Increment to Q7 to end kepler	KDMIN	F	0.5 ft/s/s
Time of flight calculation gain	KTETA	F	1000
Max L/D	LAD	F	0.3
Lateral switch bias term	LATBIAS	F	0.00012
LAD cos (15^{o})	L/DCMINR	F	0.2895
Up control L/D	LEWD	F	0.2
Final Phase L/D	LOD	F	0.18
Acceptable tolerance to stop range iteration	25NM	F	25 n.m.
Final phase range -23500 Q3	Q2	F	-1002 n.m.
Final phase dR/dV	Q3	F	0.07 n.m. /ft/s
Interval between steering updates	DT	F	2 sec

	Symbol	Memory Type	Value
Final phase dR/dGAMMAL	Q5	F	7050 n. m.
Final phase initial GAMMAL	Q6	F	0.0349
Minimum drag for up control	Q7F	F	6 ft/s/s
Limit value of VCORR	VCORLIM	F	1000 ft/s
Minimum RDOT to close loop	VRCONTRL	F	700 ft/s
Velocity to switch to relative velocity	VMIN	F	12,883 ft/s
Minimum VL	VLMIN	F	18,000 ft/s
Velocity to stop steering	VQUIT	F	1,000 ft/s
Normalization factor, acceleration	GS	F	32.2 ft/s/s
Atmosphere Scale Height	HS	F	28,500 ft
Normalization factor, velocity	VSAT	F	25,766.197 ft/sec
Nominal earth's radius (entry only)	RE	F	21,202,900 ft
Range angle to nautical mile factor	ATK	F	3437.7468 n.m /rad.
Nominal equatorial velocity	KWE	F	1546.70168 fps

6.3.6 TVC (Abort)

	Symbol	Memory Type	Value
Criterion for tumbling detection		F	5^{o}/sec
Interval: SIVB/CSM Sep. - SPS ignition (tumbling and abort		F	3.0 sec
Interval: Time-to-go-bias		F	5 sec
Interval: between steering updates		F	2.5 sec
Thrust attitude:			
X-axis above visual horizon by		F	35^{o}
(Y-axis normal to local vertical			
Z-axis above local horizontal)			
Limit: magnitude of normal acceleration		F	8 ft/s/s
Interval: Lift-off - abort target point			
(Abort from nominal mission (See Section 4.0))		E	1420 sec
Mean geo-centric radius of visual	R_{vh}	F	6.378165×10^{6} meters
Entry range angle constant		F	1,139 sec *
Entry range angle coefficient		F	2,261,239 feet *
Entry range angle critical entry velocity		F	22,000 ft/sec *
Minimum entry range coefficient		F	300 rad *

*See sec 5.3.1.

6.3.7 Entry (Abort)

	Memory Type	Value
CM Atlantic pre-entry attitude:		
X-axis above velocity vector by	F	160°
(Y-axis along neg. momentum vector ($\underline{V}*\underline{R}$)		
Z-axis above velocity vector		
A lift-vector up attitude)		
Atlantic recovery point: Latitude	E	4.00°N
Longitude	E	329.00°E

6.3.8 Free-fall time (T_f) monitor

	Memory Type	Value
Abort Entry interface altitude	F	280,000 feet
Nominal Entry interface altitude	F	400,000 feet
T_f criterion to start orientation to CM/SM Separation Attitude	F	160 sec
T_f criterion to start CM/SM Separation Sequence	F	95 sec

6.4 Vehicle Data

6.4.1 CSM Data (see also Tables 6-2 and 6-3)

Fuel equivalent slosh mass	MF	13.7 slugs
Oxidizer equivalent slosh mass	MO	44.6 slugs
Fuel mass C.G. X-location[1]	RF	970 ins to 840 ins (Apollo ref.)
Oxidizer mass C.G. X-location[1]	RO	974 ins to 840 ins (Apollo ref.)
Fuel mass natural frequency	WF	4.07[2] rad/sec
Fuel mass damping ratio	ZF	.005
Oxidizer mass natural frequency	WO	3.82[2] rad/sec
Oxidizer mass damping ratio	ZO	.005
RCS thruster moment arm	LT	6.9633 feet
Engine hinge point location	LE	833.2 ins. (Apollo ref.)
Spacecraft Launch Configuration		See Fig. 6-3

NOTES:

1. Range is from vehicle half-full to empty. A linear interpolation is assumed.
2. Data corresponds to initial thrust acceleration of 15.7 ft/sec^2 and the relation $(W^2/a_T)_t = (W^2/a_T)_{initial}$ is assumed.
3. Angles given as positive rotations of (engine hinge-point to c.g.) line about positive CSM Y and Z axes.
4. The products of inertia are assumed to satisfy:

$$\text{Angular momentum} = \begin{bmatrix} h_x \\ h_y \\ h_z \end{bmatrix} = \begin{bmatrix} I_{XX} & -I_{XY} & -I_{XZ} \\ -I_{XY} & I_{YY} & -I_{YZ} \\ -I_{XZ} & -I_{YZ} & I_{ZZ} \end{bmatrix} \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix}$$

where for example

$$I_{XY} = \int_m xy \, dm$$

Table 6-2

AS-202/AFRM 011 Mass Properties at Launch

Item	Weight (lbs.)	Center of Gravity* (inches)			Moments of Inertia** (slug-ft^2)		
		X	Y	Z	I_{xx}	I_{yy}	I_{zz}
Launch Escape System	8,450	1,299.4	0.0	-0.4	644	23,839	23,834
Command Module	11,470	1,040.4	0.0	5.1	5,803	5,123	4,582
Service Module (less propellant)***	10,365	911.0	1.0	-0.5	6,453	10,866	10,543
Total Usable SPS Propellant	22,950	911.2	26.2	-11.1	7,950	12,750	14,100
Spacecraft LEM Adapter	3,600	642.4	1.7	-3.7	8,758	11,849	11,553

*Centers of gravity are in the NASA reference system, except that the longitudinal axis origin is 1,000 inches below the tangency point of the Command Module substructure mold line.

**Moments of inertia are about the item center of gravity.

***Includes unusable SPS and RCS trapped, mixture ratio tolerance, loading tolerance, RCS propulsion efficiency tolerance and SPS restart loss propellants. Includes usable RCS propellants (see Table 6-3).

Table 6-3

AS-202/AFRM 011 Expendable Items Mass Properties Data

Item	Weight (lbs)	Center of Gravity* (inches)			Moments of Inertia** (slug-ft^2)		
		X	Y	Z	I_{xx}	I_{yy}	I_{zz}
LES Main and Pitch Motor Propellants	3,192	1,295.3	0.0	0.0	71	1,280	1,280
SPS Propellant							
-Usable for Mission Delta V	22,050	See Figs. 6-4 through 6-9					
-Usable Reserve	600						
-Unusable Ballast Required	300						
SLA Jettisoned***	3,535	639.0	1.7	-3.7	8,681	11,293	10,999
CM RCS Usable Propellant	225	1,022.6	-5.6	57.0	49	4	45
SM RCS Usable Propellant	790	959.0	0.0	0.0	752	460	415
Ablator Burn-off During Entry-Total	101	1,008.9	0.0	10.1	75	37	37
Forward Heat Shield Jettisoned	395	1,100.5	-0.4	1.3	66	53	53
Drogue Chutes	63	1,090.3	0.0	-20.9	1	1	2
Main Chutes (3)	409	1,090.5	-0.8	6.4	49	21	37

*Centers of gravity are in the NASA reference system, except that the longitudinal axis origin is 1,000 inches below the tangency point of the Command Module substructure mold line.

**Moments of inertia are about the item center of gravity.

NOTES: RCS propellant centers of gravity do not vary with propellant load variation.

***SLA Ring retained with Service Module

Item	Weight (lbs.)	Center of Gravity (inches)			Moments of Inertia (slug-ft^2)		
		X	Y	Z	I_{xx}	I_{yy}	I_{zz}
Ring	65	837.1	0.0	-1.8	77	40	38

[redacted]

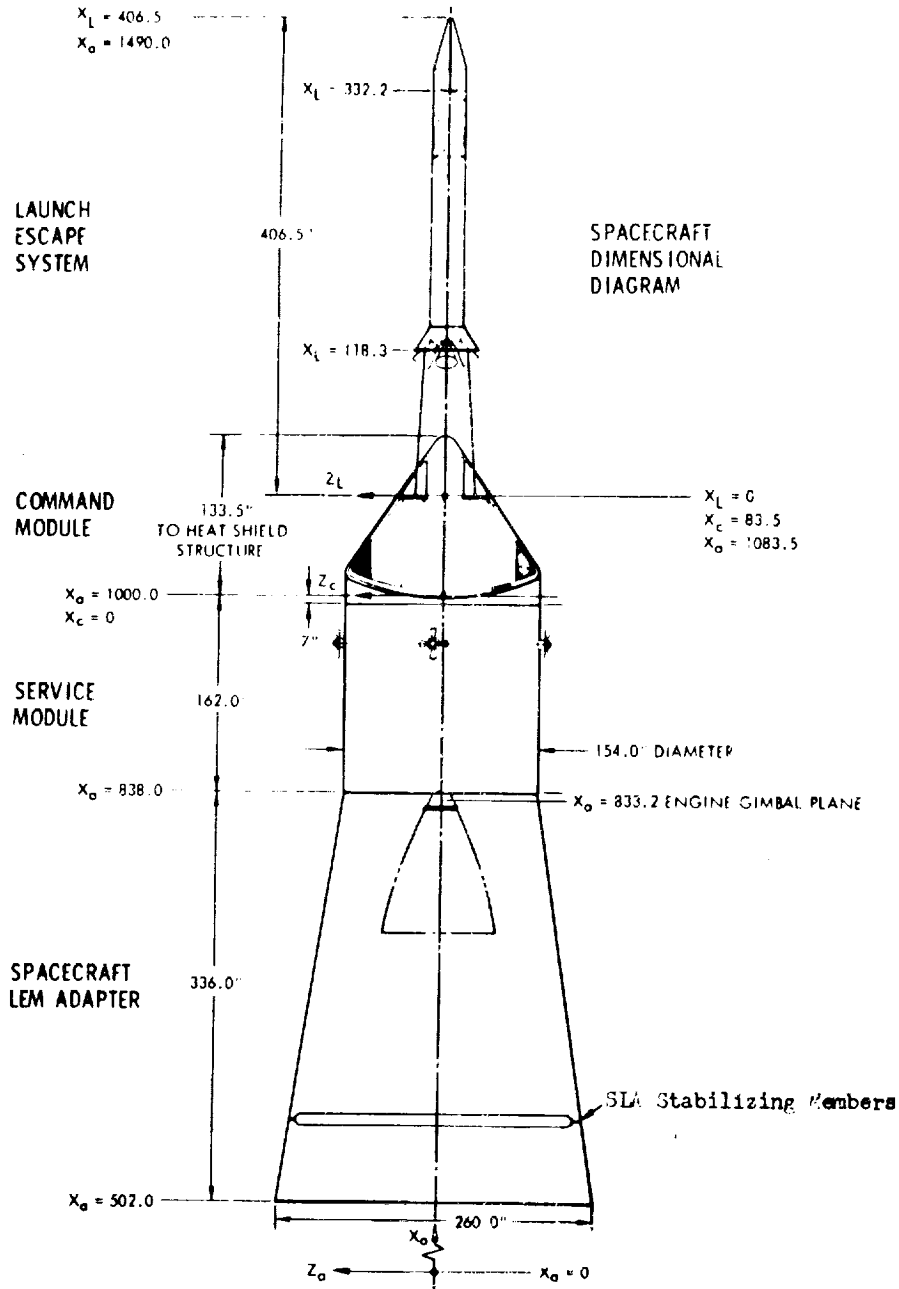


Fig. 6-3 CSM Launch Configuration

[redacted]

[redacted]

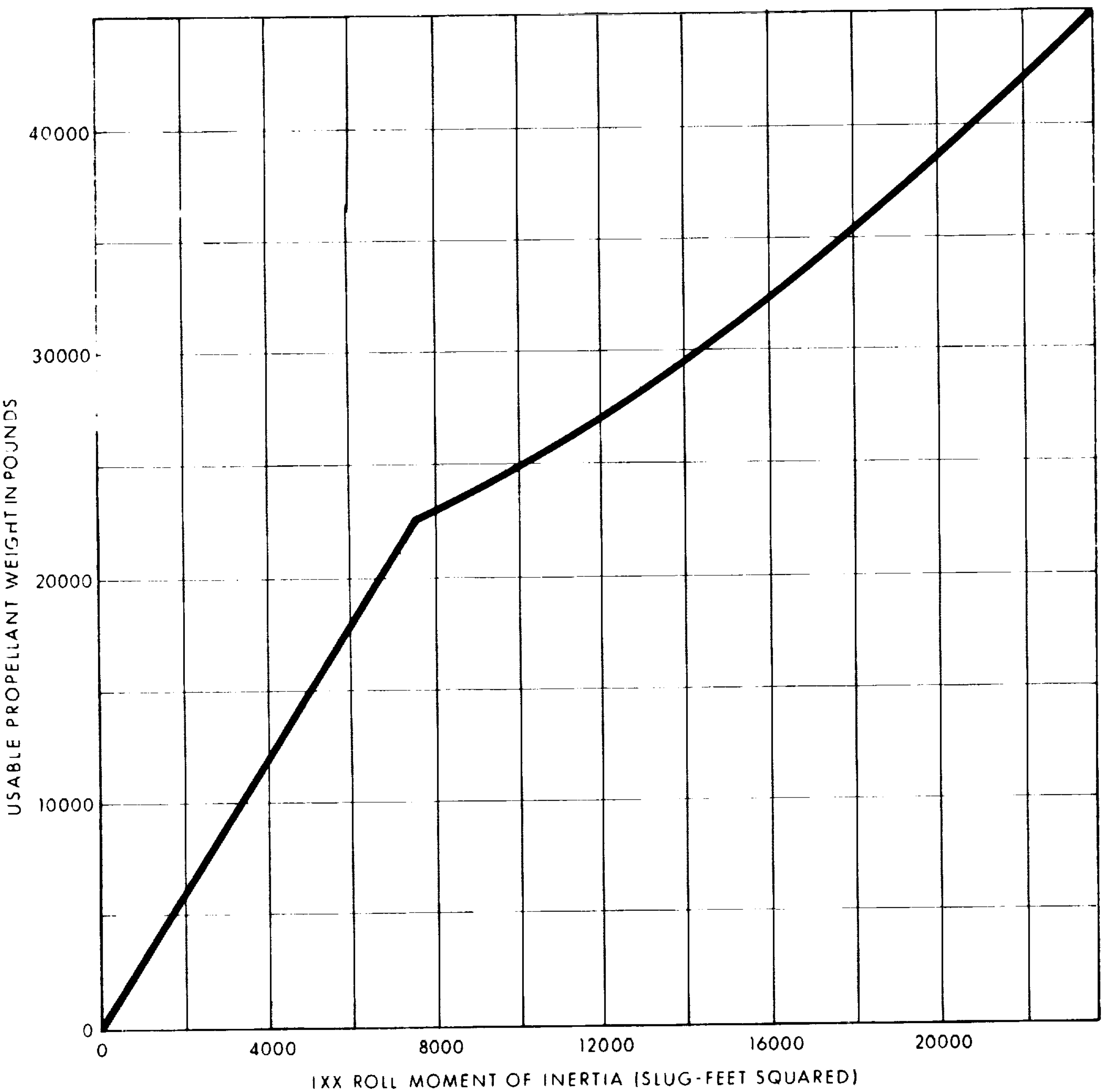


Fig. 6-4

[redacted]

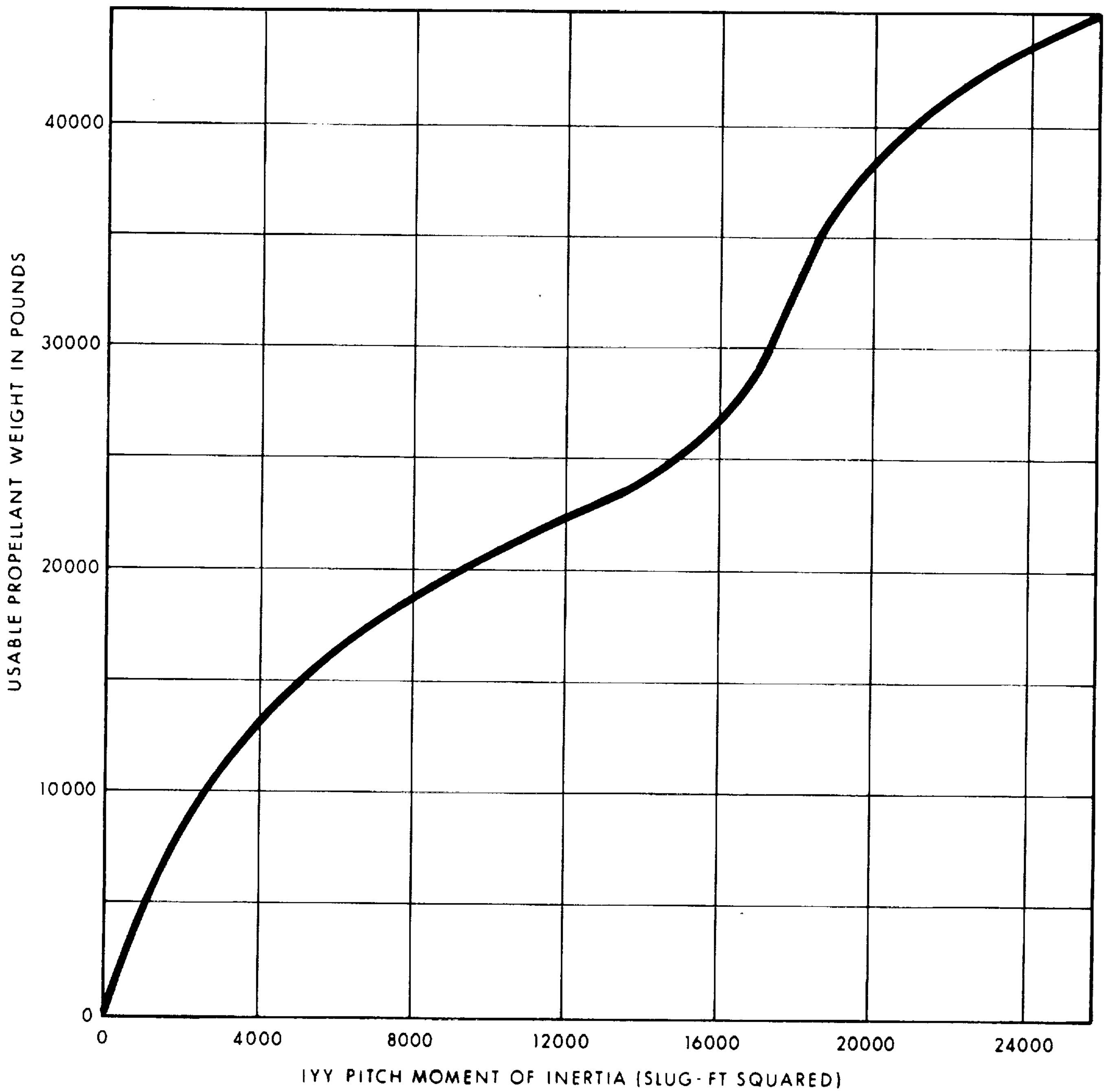

USABLE PROPELLANT WEIGHT IN POUNDS
40000
30000
20000
10000
0
0
4000
8000
12000
16000
20000
24000
IYY PITCH MOMENT OF INERTIA (SLUG-FT SQUARED)

Fig. 6-5

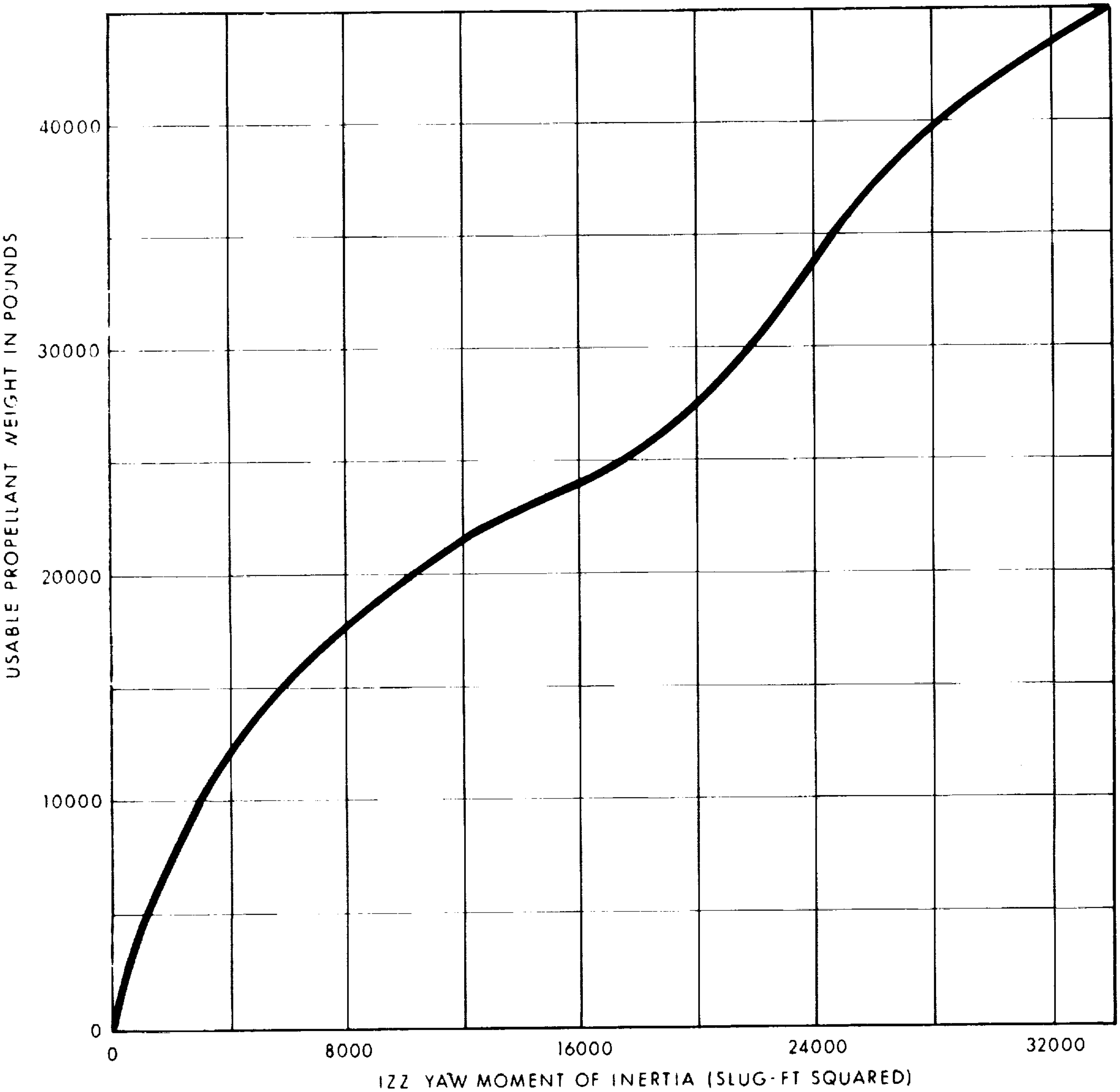

USABLE PROPELLANT WEIGHT IN POUNDS
40000
30000
20000
10000
0
0
8000
16000
24000
32000
IZZ YAW MOMENT OF INERTIA (SLUG-FT SQUARED)

Fig. 6-6

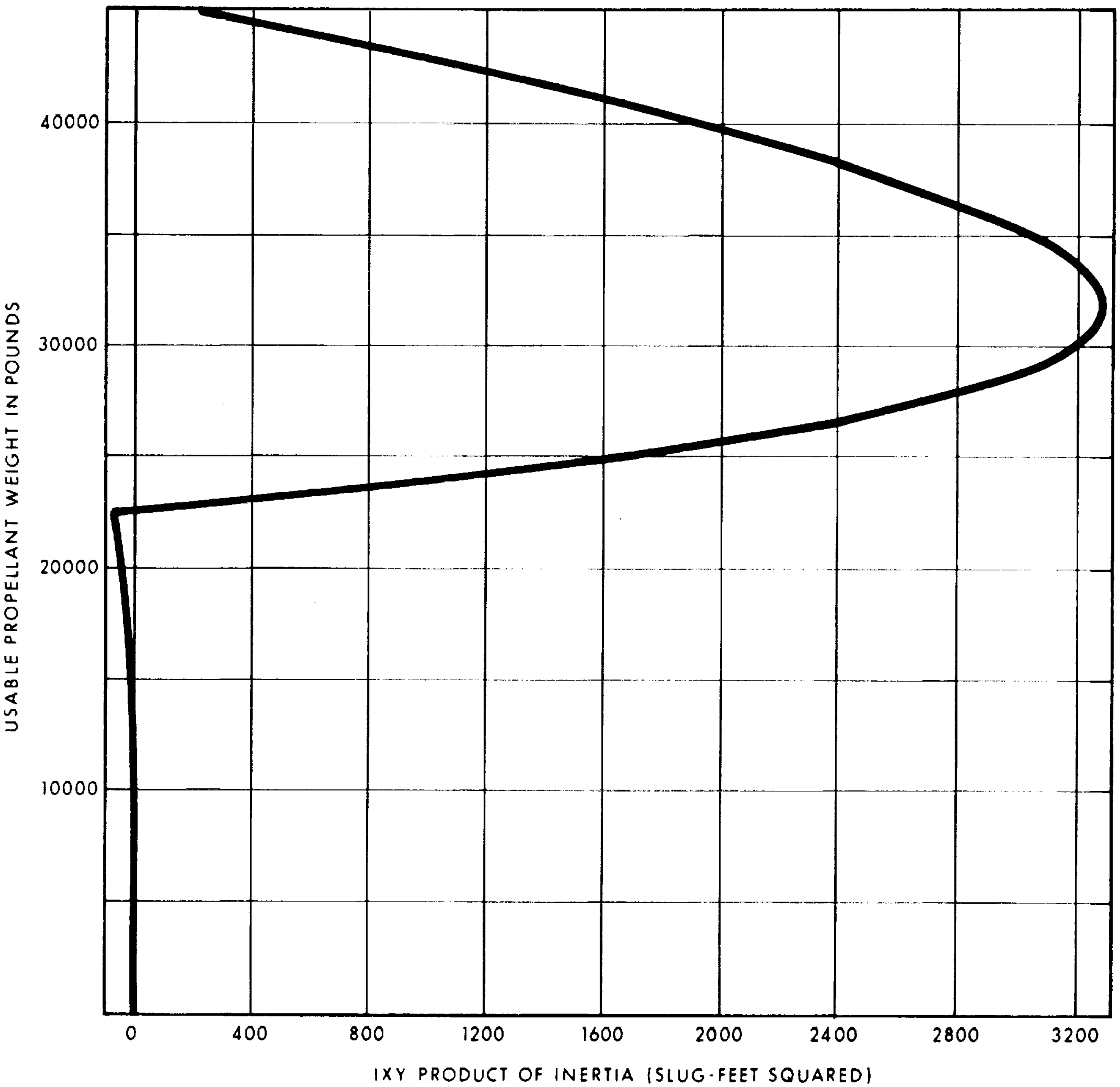

40000
30000
20000
10000
USABLE PROPELLANT WEIGHT IN POUNDS
0
400
800
1200
1600
2000
2400
2800
3200
IXY PRODUCT OF INERTIA (SLUG-FEET SQUARED)

Fig. 6-7

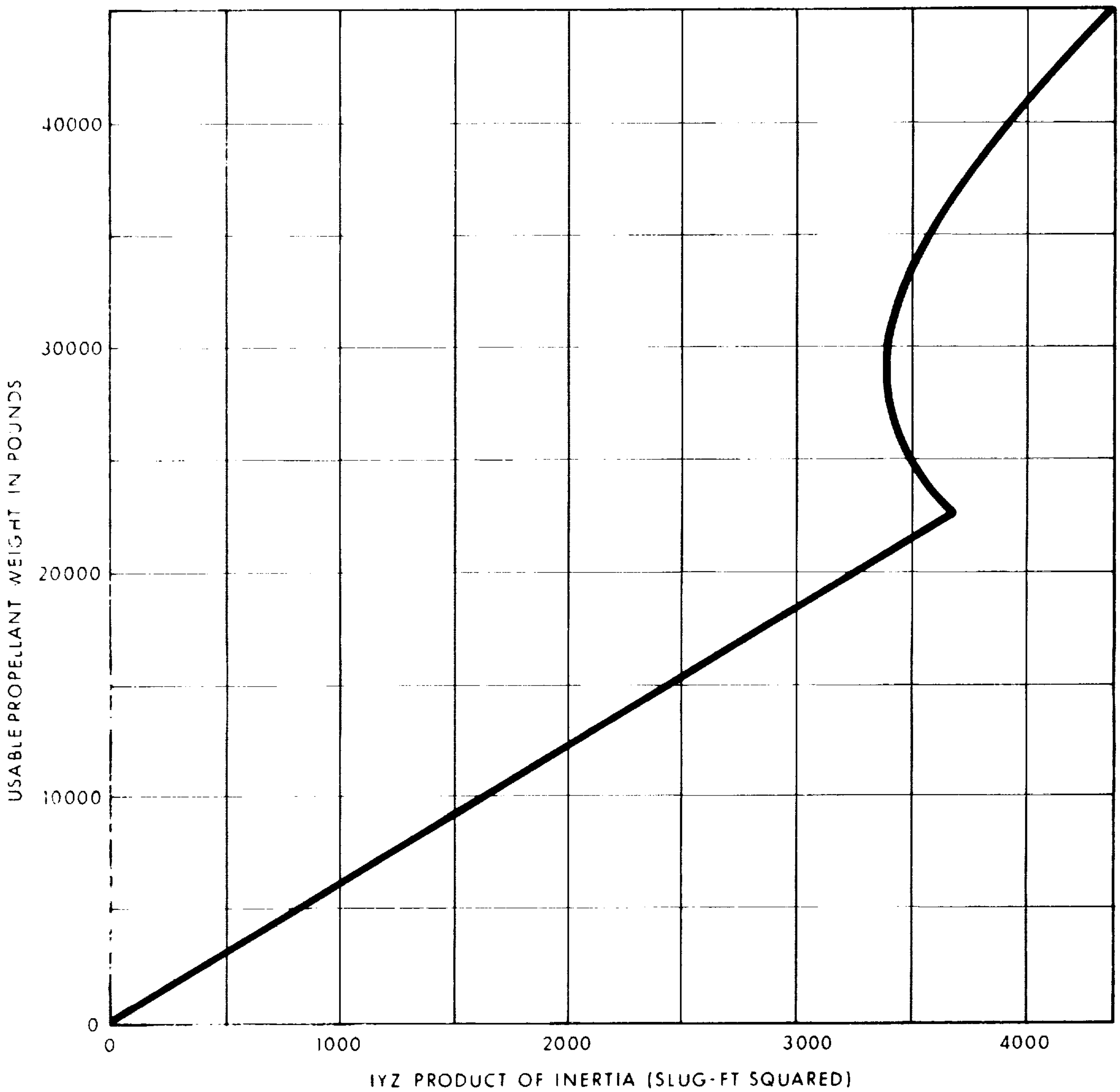

USABLE PROPELLANT WEIGHT IN POUNDS
40000
30000
20000
10000
0
0
1000
2000
3000
4000
IYZ PRODUCT OF INERTIA (SLUG-FT SQUARED)

Fig. 6-8

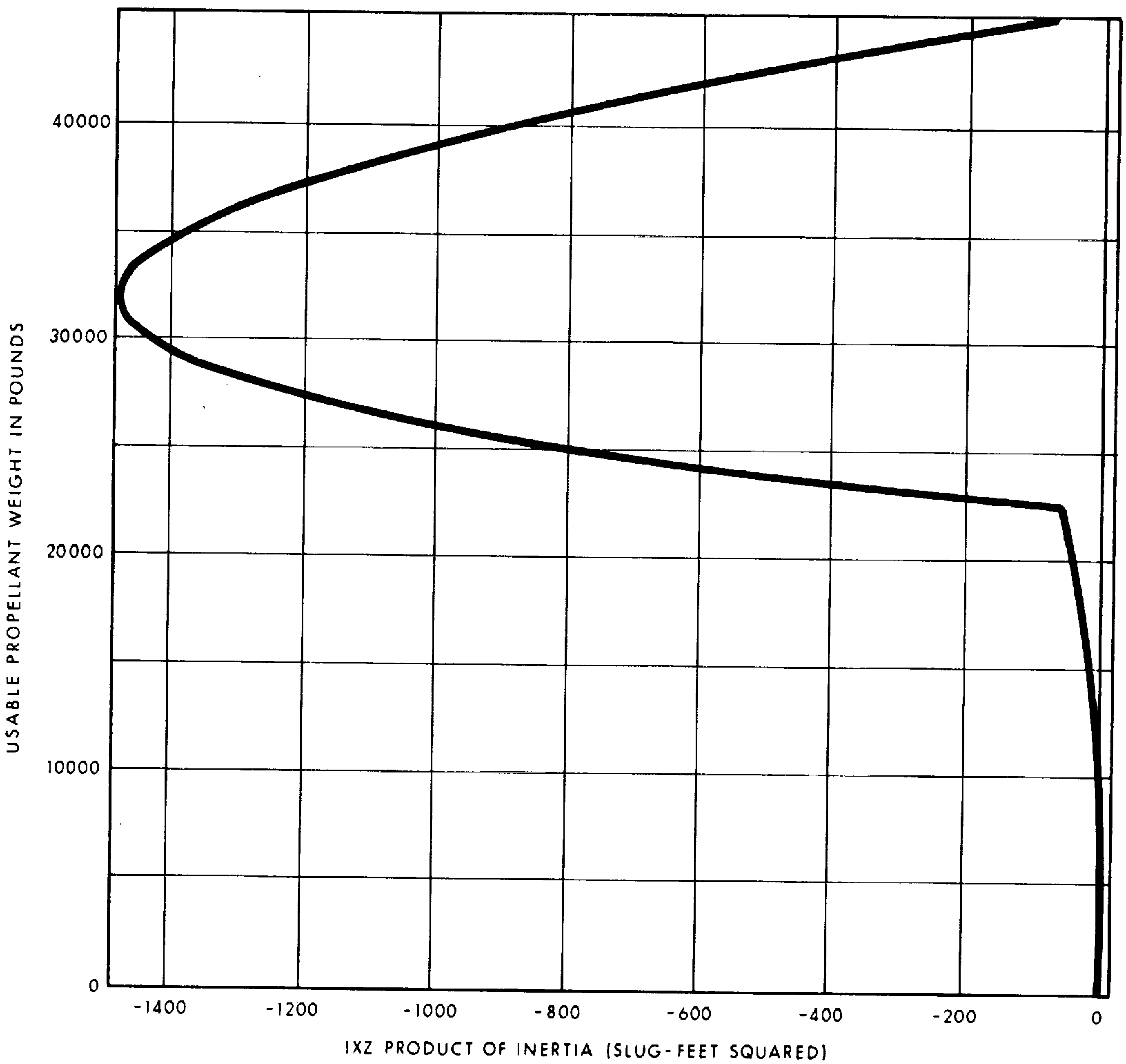
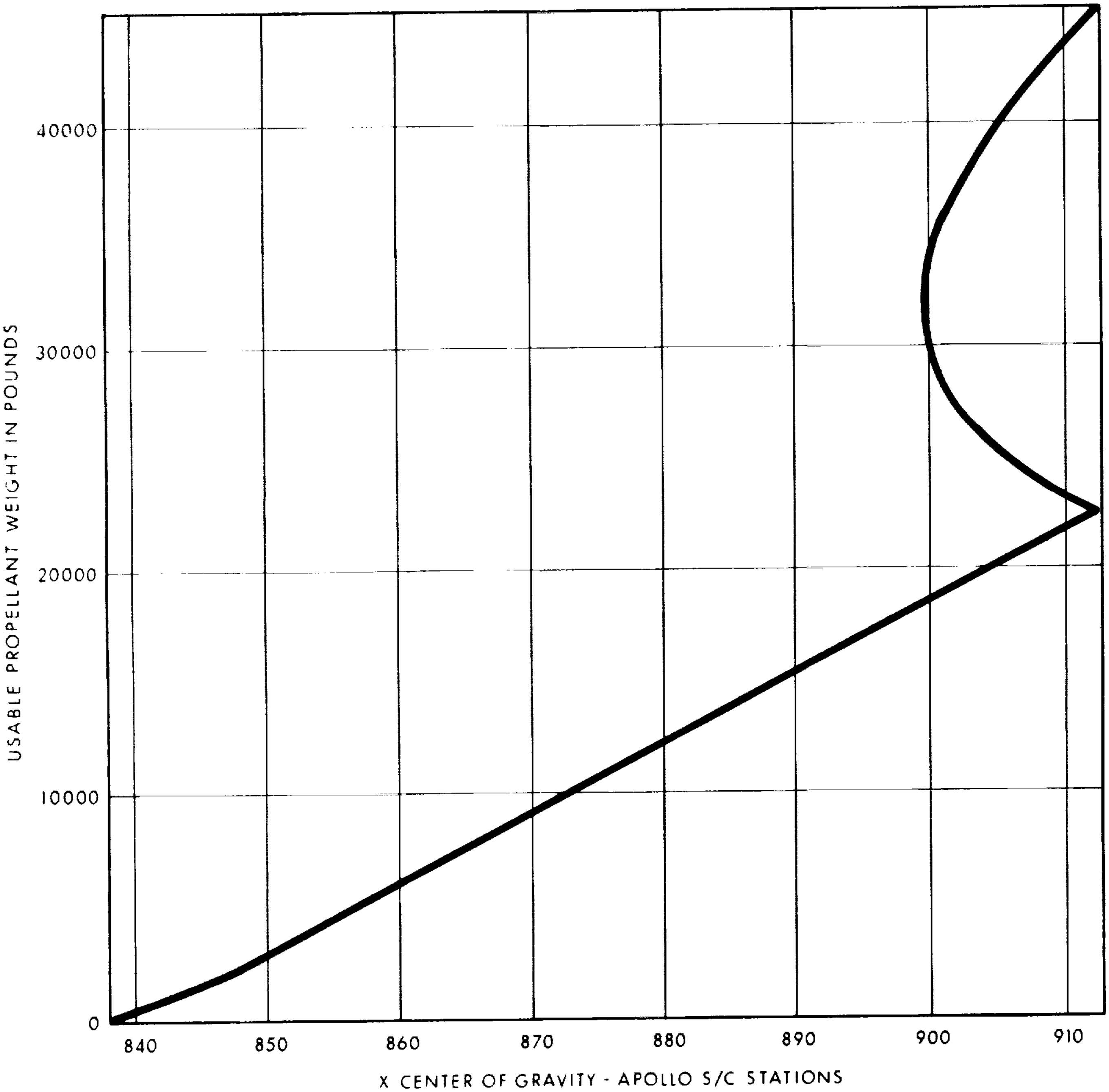
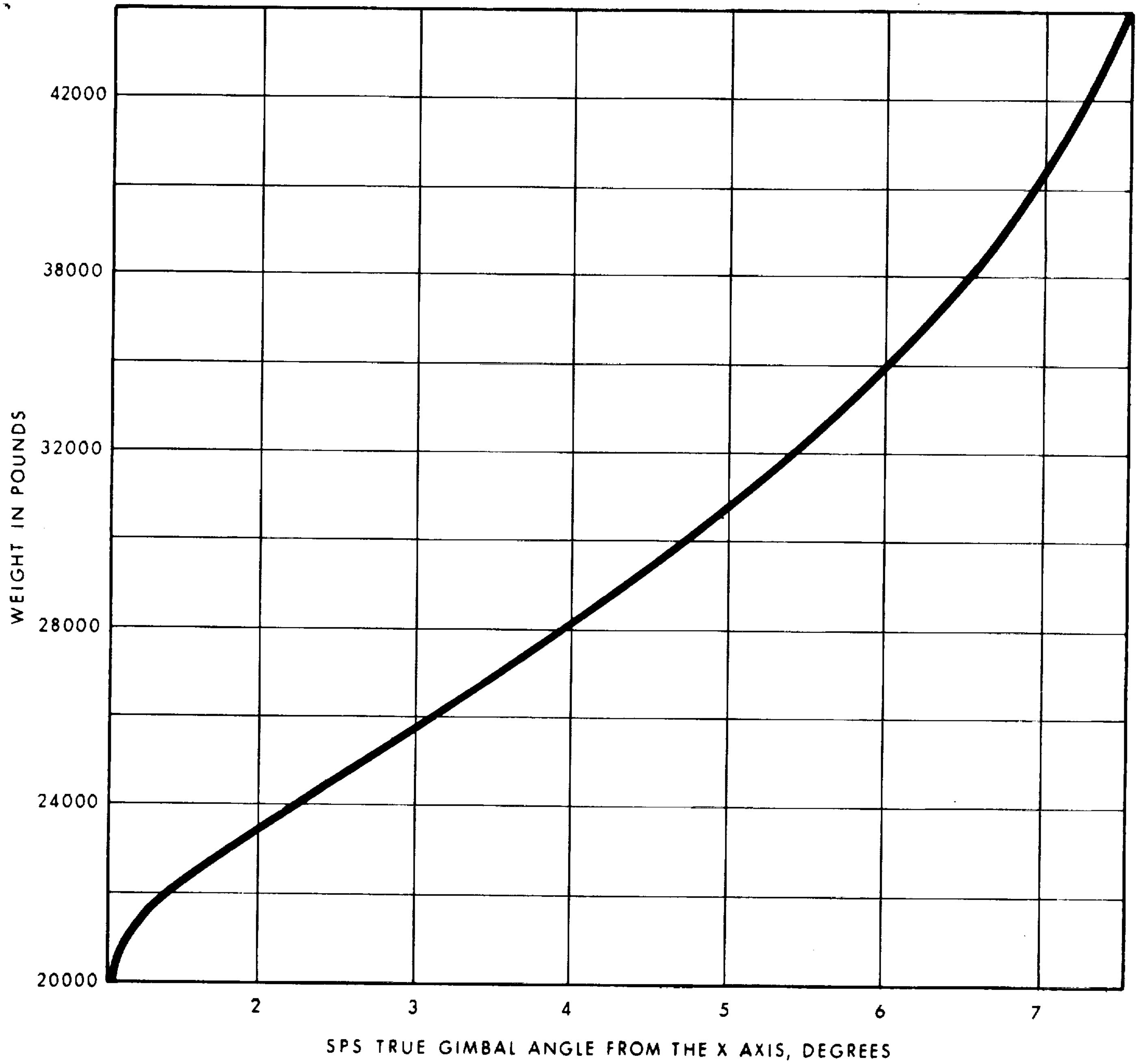

USABLE PROPELLANT WEIGHT IN POUNDS
40000
30000
20000
10000
0
-1400
-1200
-1000
-800
-600
-400
-200
0
IXZ PRODUCT OF INERTIA (SLUG-FEET SQUARED)

Fig. 6-9



USABLE PROPELLANT WEIGHT IN POUNDS
40000
30000
20000
10000
0
840
850
860
870
880
890
900
910
X CENTER OF GRAVITY - APOLLO S/C STATIONS

Fig. 6-10



42000
38000
32000
28000
24000
20000
WEIGHT IN POUNDS
2
3
4
5
6
7
SPS TRUE GIMBAL ANGLE FROM THE X AXIS, DEGREES

Fig. 6-11

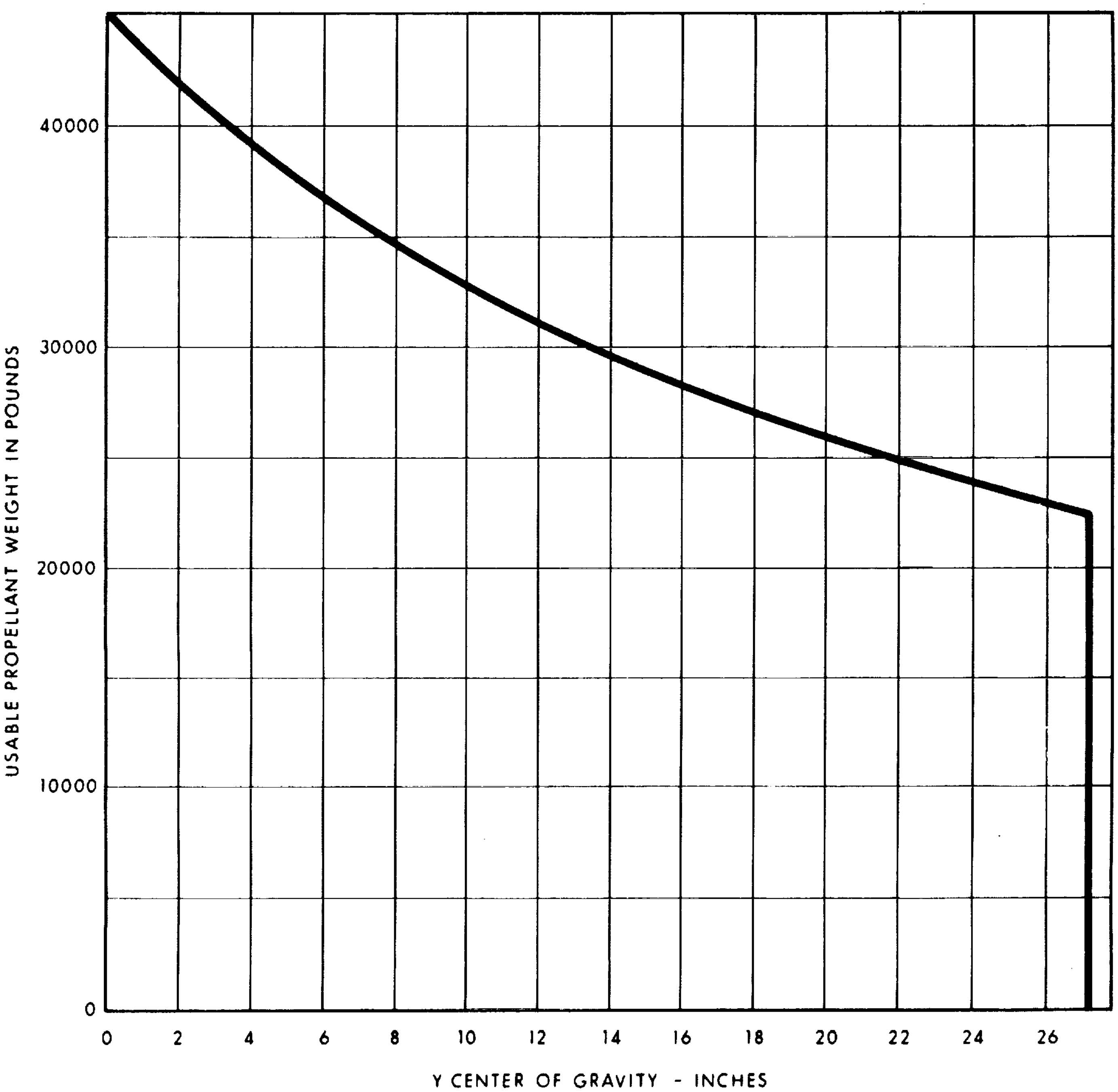
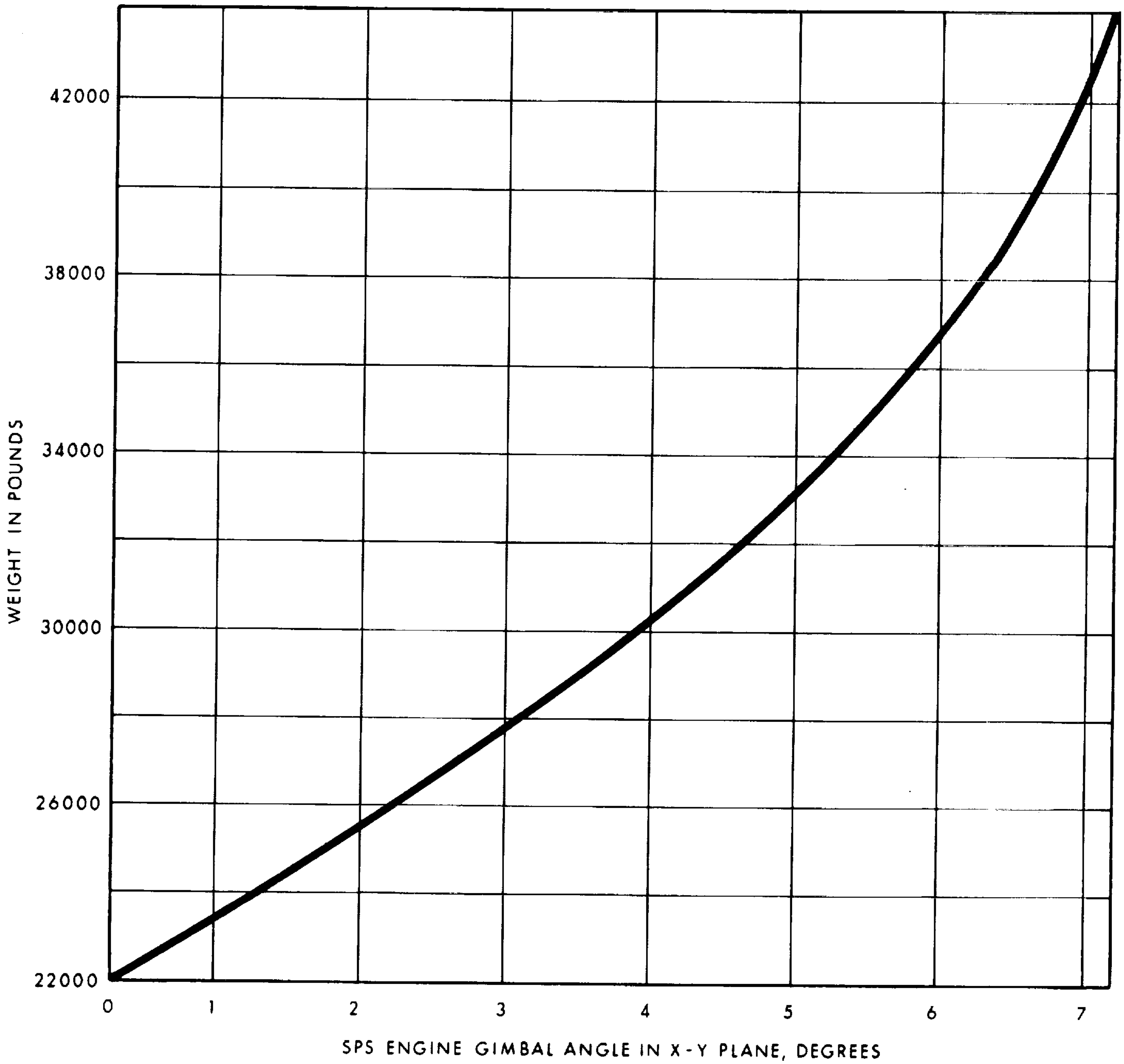

USABLE PROPELLANT WEIGHT IN POUNDS
40000
30000
20000
10000
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Y CENTER OF GRAVITY - INCHES

Fig. 6-12



WEIGHT IN POUNDS
42000
38000
34000
30000
26000
22000
0
1
2
3
4
5
6
7
SPS ENGINE GIMBAL ANGLE IN X-Y PLANE, DEGREES

Fig. 6-13

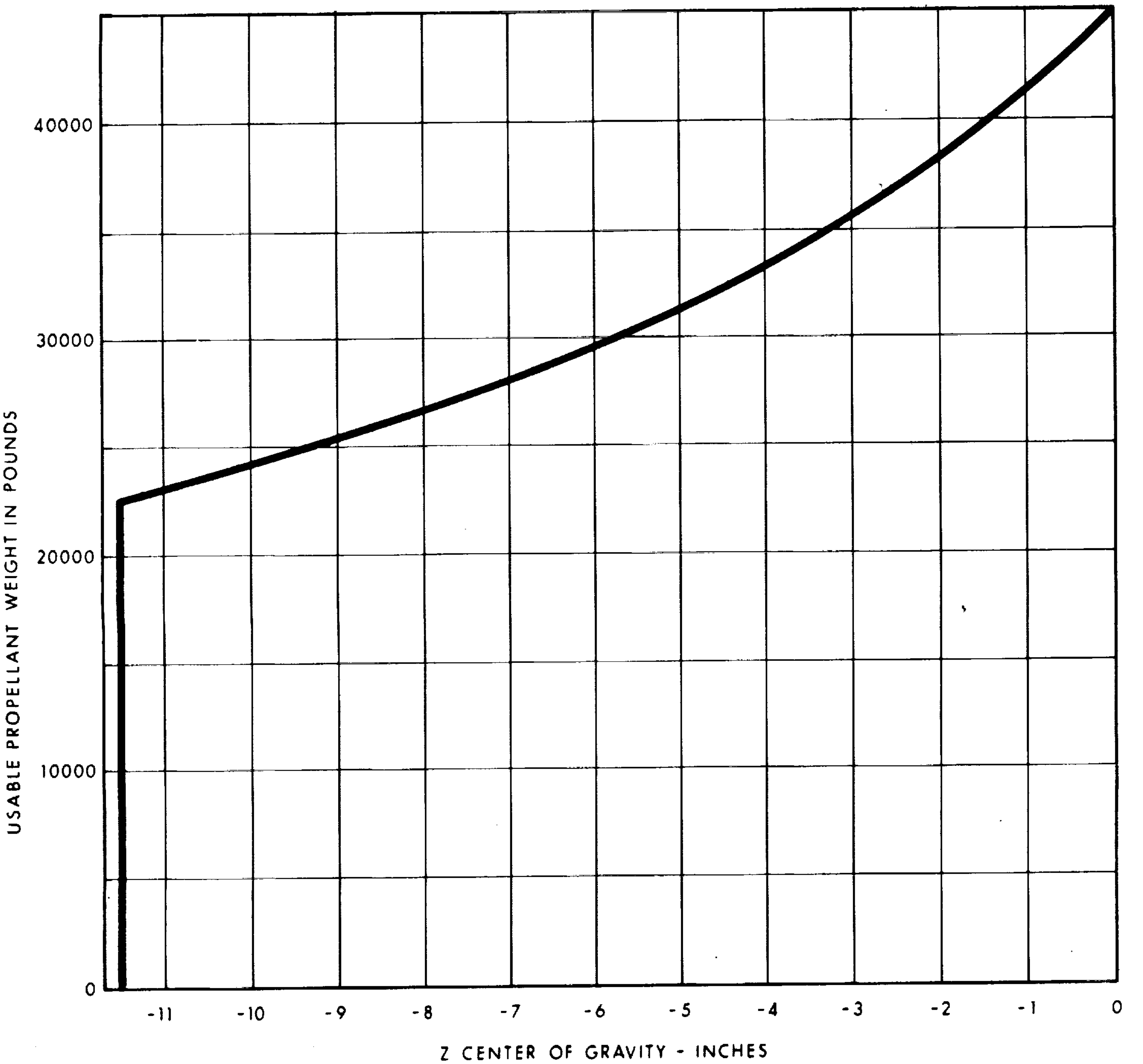
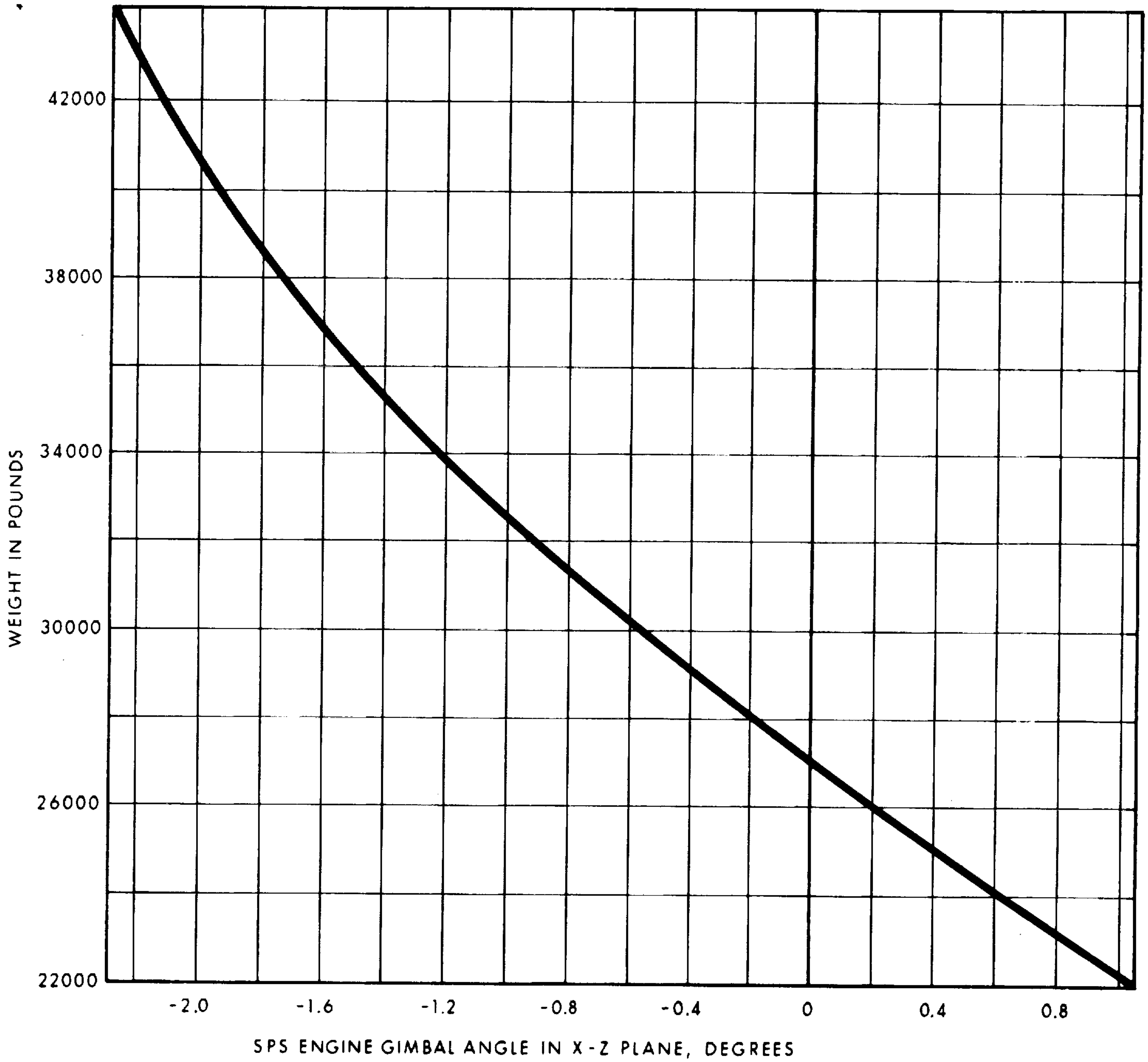

40000
30000
20000
10000
0
USABLE PROPELLANT WEIGHT IN POUNDS
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
Z CENTER OF GRAVITY - INCHES

Fig. 6-14



42000
38000
34000
30000
26000
22000
WEIGHT IN POUNDS
-2.0
-1.6
-1.2
-0.8
-0.4
0
0.4
0.8
SPS ENGINE GIMBAL ANGLE IN X-Z PLANE, DEGREES

Fig. 6-15

6.4.2 SPS Engine Data

Item	Symbol	Value
Mass	ME	25 slugs
Hinge to c.g. radius	LE	2.0 inches
Vacuum thrust	TF	21,500 lbs
		(± 1% after 30 sec)
		($^{+10\%}_{-1\%}$ after 750 sec)
Specific impulse	ISP	317.8 ± 4.8 secs (3σ variation)
Maximum start and shutdown transients		See Fig. 5.16
Mean thrust-off impulse		11,350 lb-sec
Displacement, thrust vector from engine gimbal axes intersection		<0.125 inches
Misalignment, thrust vector from engine mount plane normal		<0.5 deg.

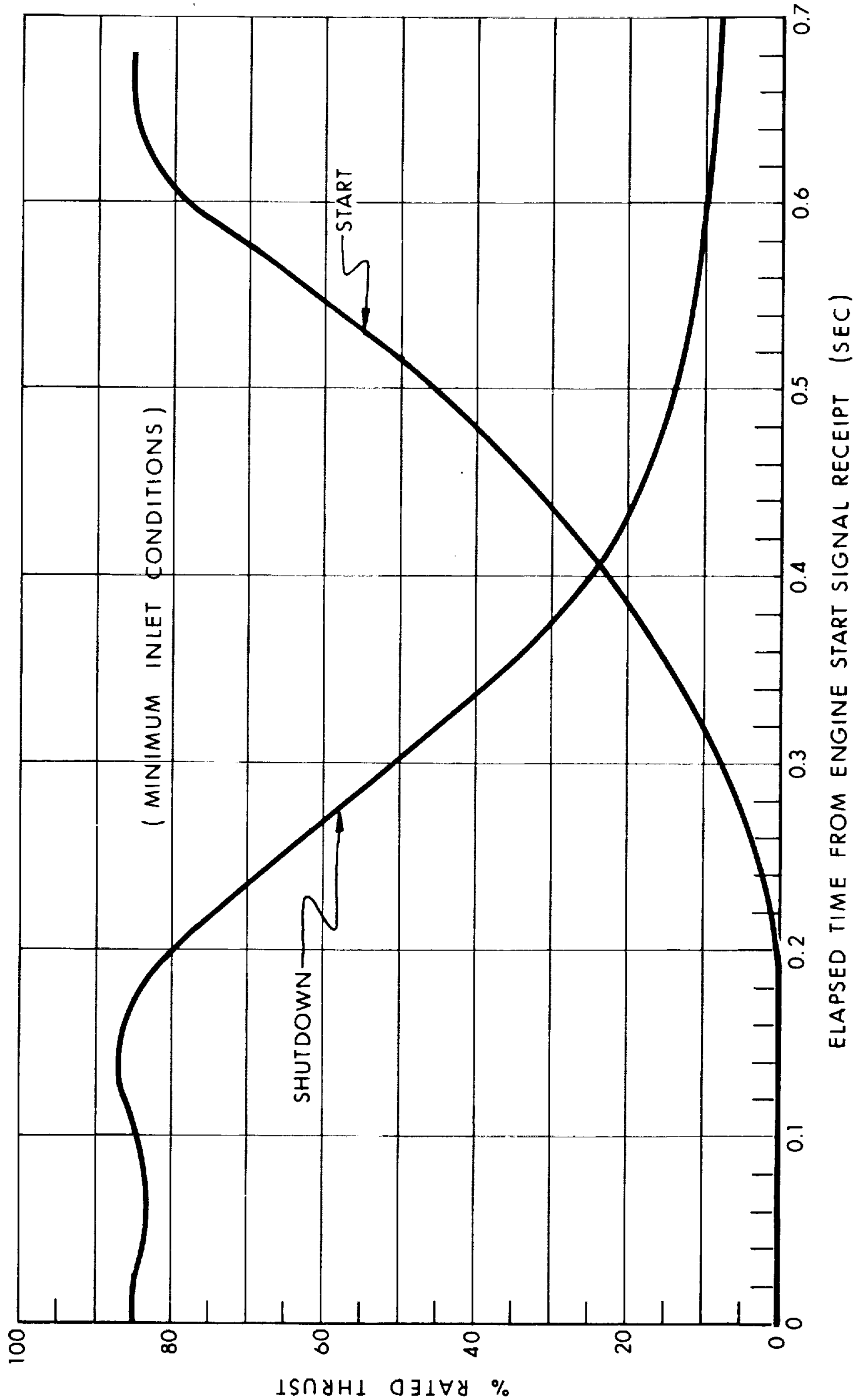


Fig. 6-16 SPS Engine Start and Shutdown Transients.

6.4.3 TVC Autopilot Data

TVC Autopilot Data	Symbol	Pitch (Y)	Yaw (Z)	Units
Configuration		Defined in Fig. 6.17		
Attitude error gain	KA	1.00		rad/rad
Attitude rate gain	KR	0.500		rad/rad/sec
Rate command limit	L	0.140		rad
		(effectively 16°/sec)		
Att. rate filter lead time constant	τ_1	0.125		sec
Att. rate filter lag time constant	τ_2	0.042		sec
Forward filter gain	KE	1.50		
Forward filter frequency	WE	42.4		rads/sec
Forward filter damping ratio	ζ_E	0.5		N. d.
Commanded position breakpoint	LMP(1)	0.105		rads(6°)
Commanded position limit	LMP(2)	0.227		rads(13°)
Clutch servo amplifier gain	KS	20.0		Amps/rad
Clutch servo amp. lead time const.	τ_3	0.025		sec
Clutch servo amp. lag time const.	τ_4	0.029		sec
Clutch servo current limit	LMI	0.600		Amps
Clutch gain	KC	3,530		lbs/amp
Actuator moment arm	RA	1.00	1.05	feet
Clutch lead time constant	τ_5	0.022		sec
Clutch lag time constant	τ_6	0.029		sec
Total actuator load inertia	JT	301	308	slug-ft^2
Actuator load time constant	WA	6.652	6.499	1/sec
Actuator load natural frequency	WB	104	81.7	rad/sec
Actuator load damping ratio	ζ	0.104	0.137	
Engine rate limit	LMR	0.300		rad/sec
Engine position limit (pitch)	LMY	±0.105		rad(±6°)
Engine position limit (yaw)	LMZ		+0.192 -0.052	rad($^{+11.0^{\circ}}_{-3.0^{\circ}}$)
Position feedback gain	KD	1.00		rads/ft/sec
Position pickoff frequency	WD	63.0	46.2	
Rate feedback gain	KG	0.090		rads/ft
Rate pickoff frequency	WC	48.1	40.0	rads/sec

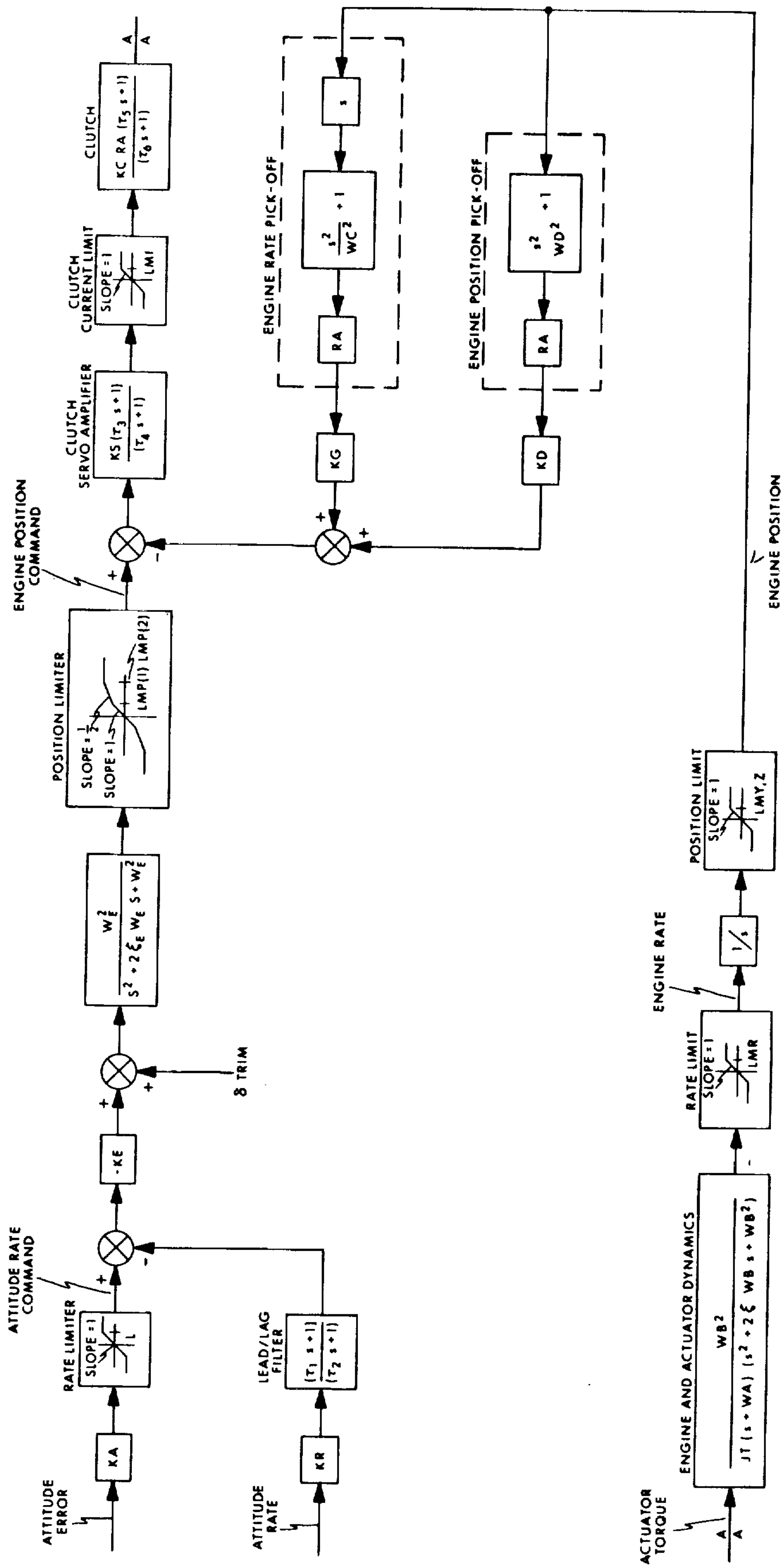


Figure 6-17 TVC Autopilot Block Diagram

6.4.4 RCS Autopilot Data

			Att. Cont.	TVC	Pre-05g		Entry	
Configuration: see Fig. 6-13			Roll,[6] Pitch, Yaw	Roll[6]	Roll	Pitch, Yaw	Roll	Pitch, Yaw
Attitude error deadband	D	Degrees	0	0	4.0		4.0	---(1)
Attitude error gain	GA	Deg/sec per deg	1.0	1.0	0.2		0.2	---(1)
Rate command limiter	E	Deg/sec	---(3)	---(3)	1.9[4]	0.7[5]	1.9[4]	---(1)
Rate Gain	GR	n.d.	1.0	1.0	0.1		0.1	
Roll-to-yaw coupling angle	ALPHA	Degrees	---	---	---		22°	
Filter gain } See Note (2)	K	Deg/sec	---	---	---		---	
Filter Time constant } See Note (2)	τ_f	sec	---	---	---		---	
Switch Deadband	A	Deg/sec	0.2	0.2	0.2		0.2	
	B	Deg/sec	A-0.007	A-0.007	A-0.007		A-0.007	

NOTES

1. Pitch, yaw attitude error channels open-circuited during entry.
2. Filter feedback open-circuited for AS - 202.
3. Effective attitude rate limit set by saturation of electronics at approximately 9.3°/sec. Commanded rates will be limited to 4°/sec (pitch, yaw) 7.2°/sec (CSM-roll) 15°/sec (CM only-roll)
4. Effective attitude rate limit (roll): 17°/sec
5. Effective attitude rate limit (pitch, yaw): 5°/sec
6. CSM roll control uses four jet clusters

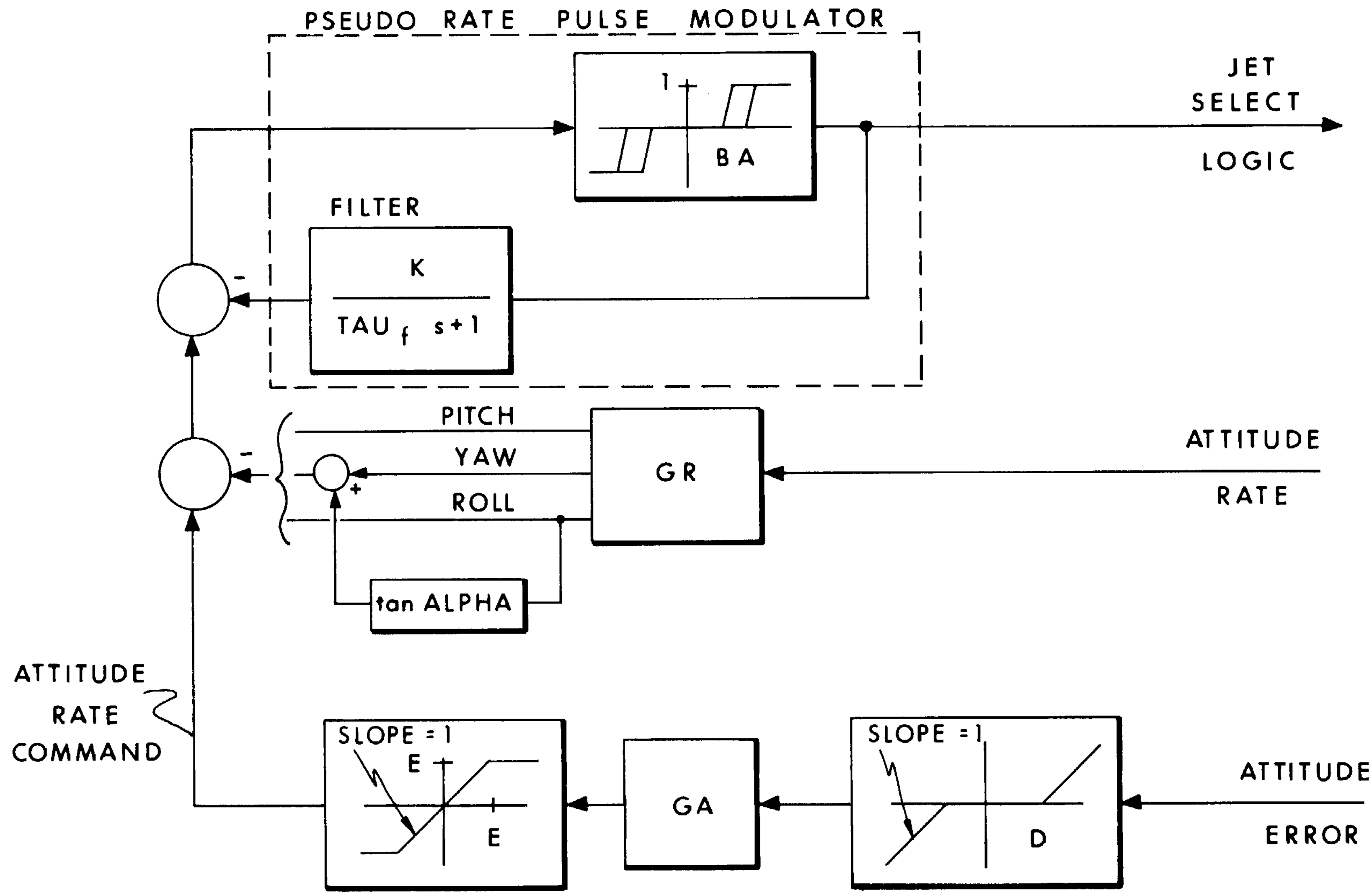


Fig. 6-18 RCS Autopilot Block Diagram.

6.4.5 RCS Reaction Jet Data

Item	Units	Value SM	Value CM
Configuration		(see Fig. 6.19)	(see Fig. 6.20)
Nominal vacuum thrust	lbs	100 ± 2.5	92.9 ± 2
Specific impulse (steady)	secs	280 ± 7.6	274 + 3.3
Minimum impulse	lb-sec	0.75 ± 0.15	1.5 + 0.5
Thrust rise lag	millisec	<12.5	<13.0
Thrust rise time constant	millisec	2.0 (exp)	2.0 (linear)
Duration, minimum impulse electrical signal	millisec	18.0 ± 4.0	18.0 ± 4.0
Engine cant angle	deg	10.0	

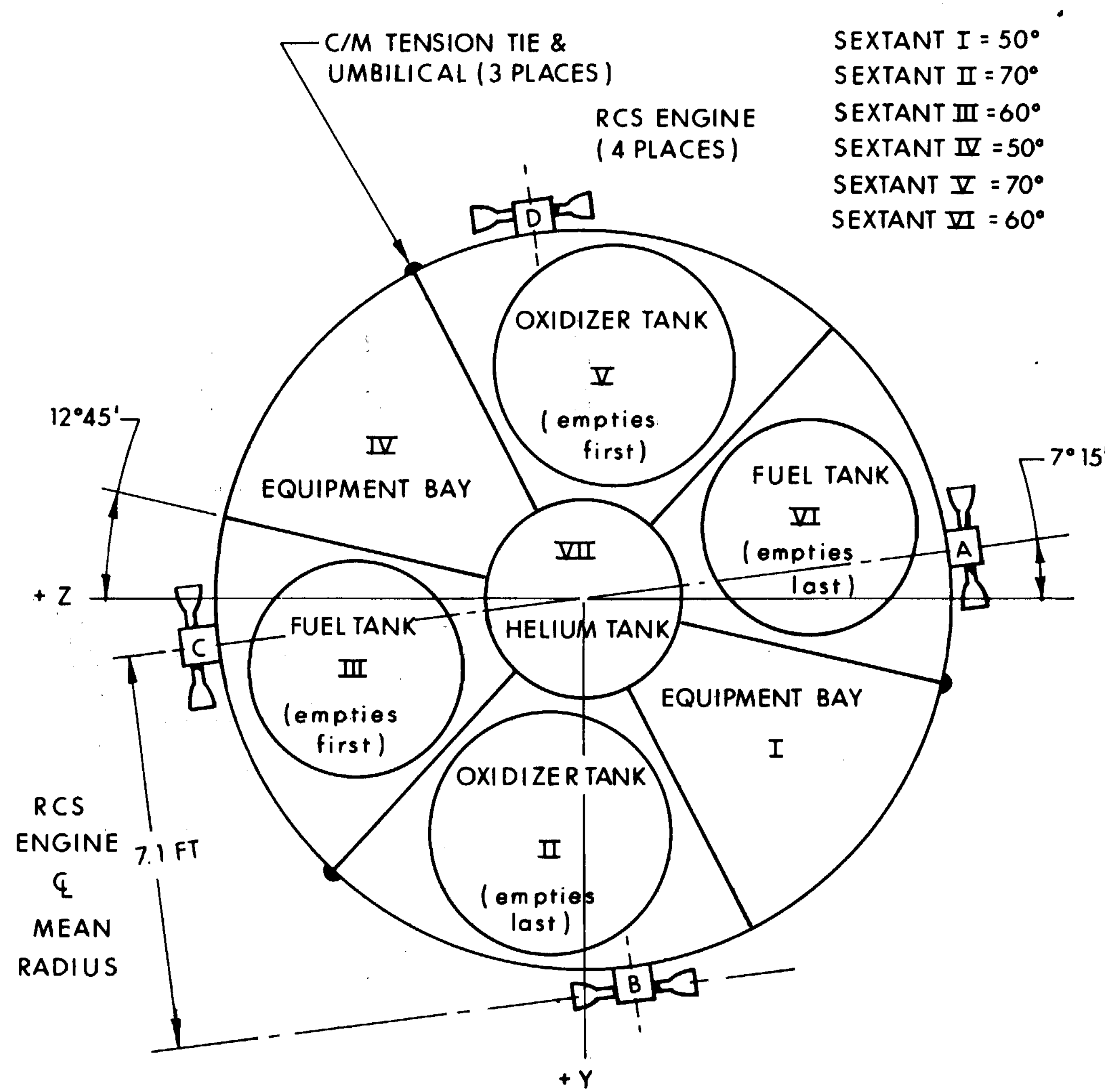


Fig. 6-15. CSM Reaction Jet Positions.

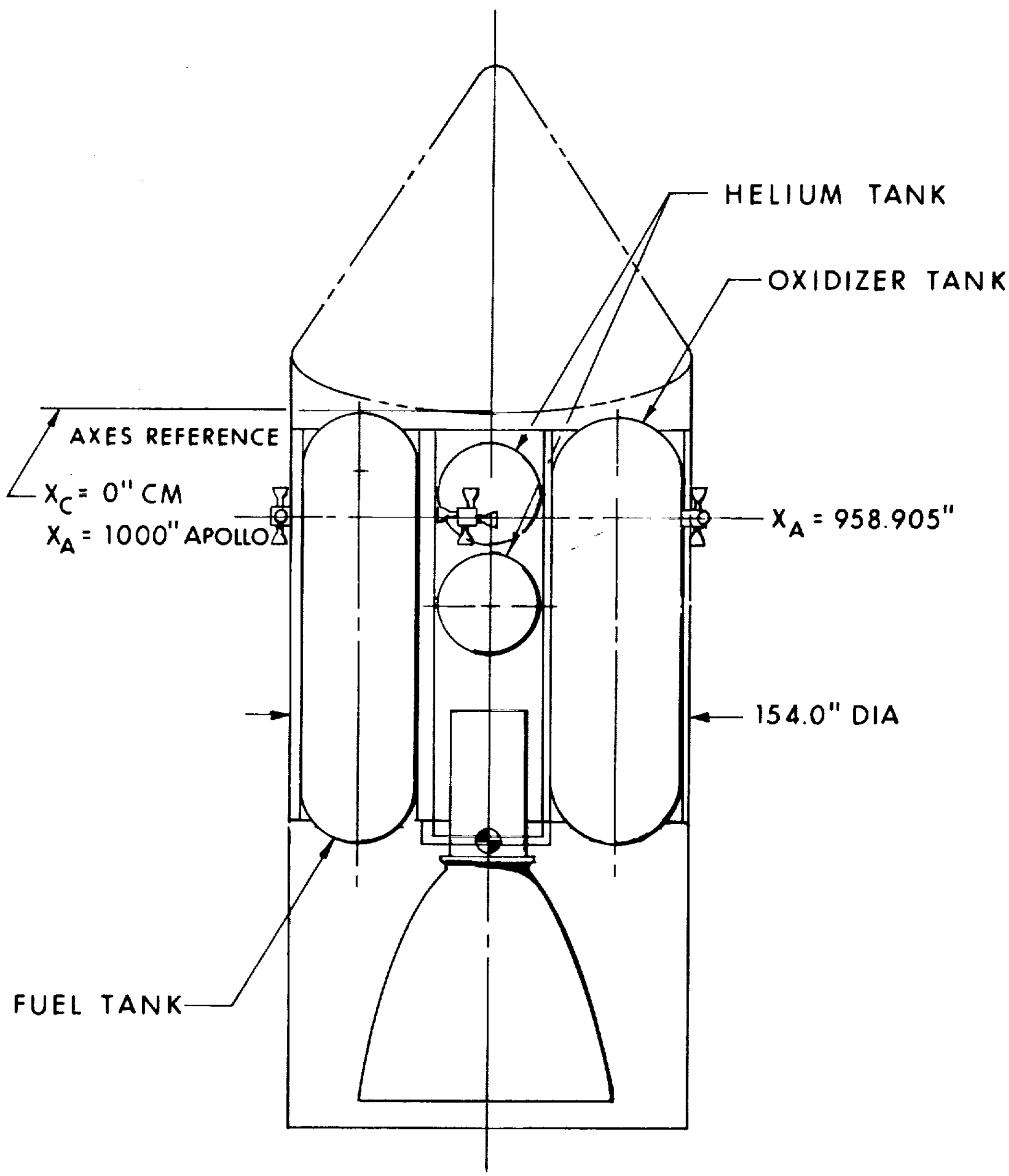
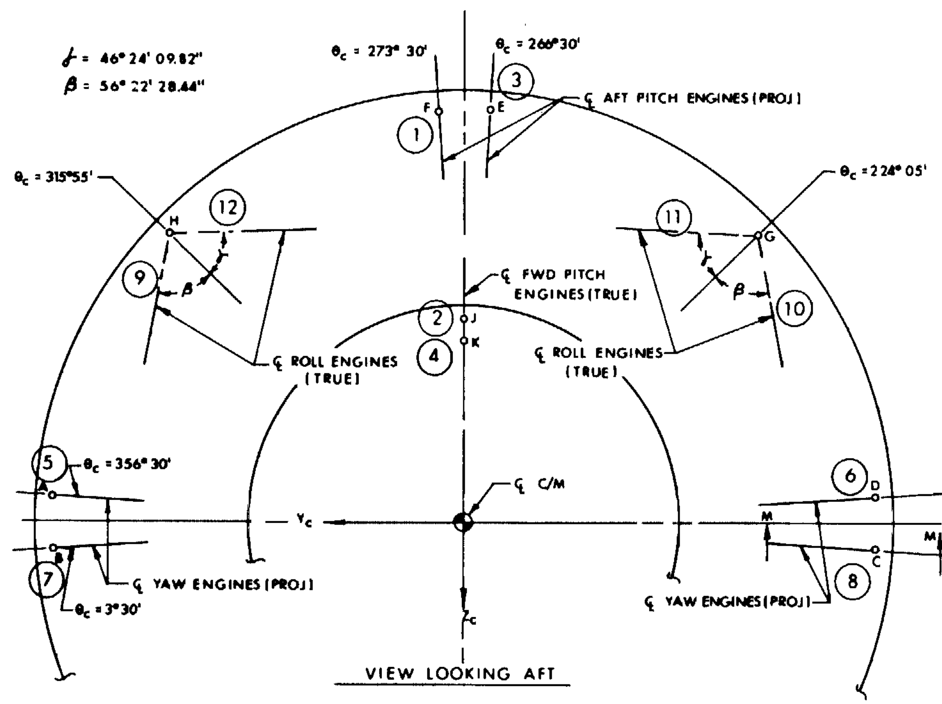
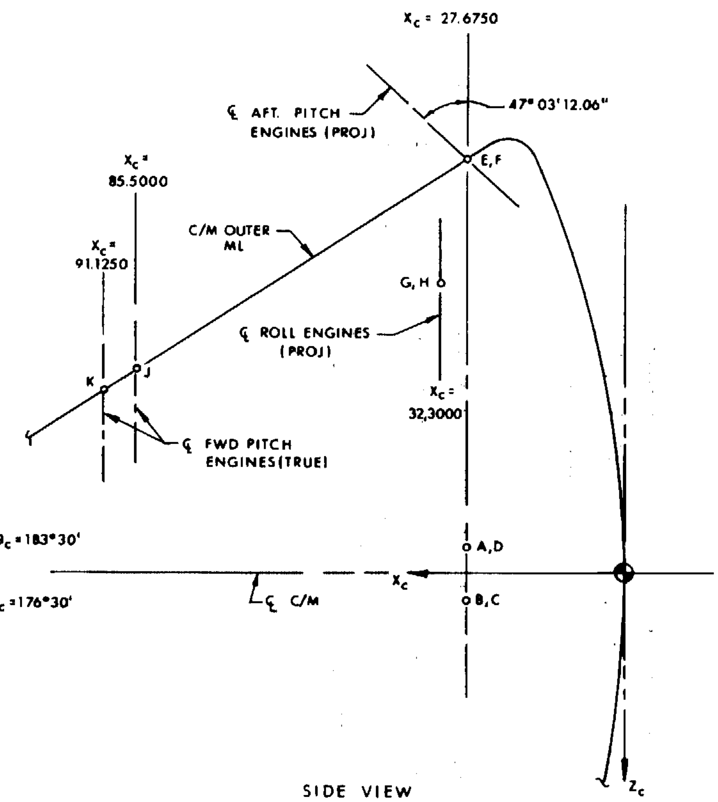


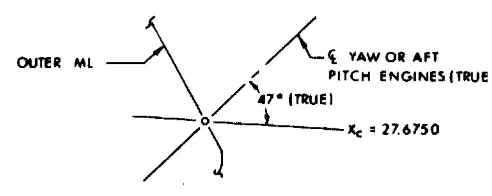
Fig. 6-19 (2) CSM Reaction Jet Positions.





	X_c	Y_c	Z_c	R_c
A	27.6750	72.2846	- 4.4211	72.4197
B	27.6750	72.2846	4.4211	72.4197
C	27.6750	-72.2846	4.4211	72.4197
D	27.6750	-72.2846	- 4.4211	72.4197
E	27.6750	- 4.4211	- 72.2846	72.4197
F	27.6750	4.4211	- 72.2846	72.4197
(1) G	32.3000	- 51.9826	- 50.3454	72.3661
(1) H	32.3000	51.9826	- 50.3454	72.3661
J	85.5000	0	- 35.5483	35.5483
K	91.1250	0	- 31.9616	31.9616

NOTES: (1) NOT ON OUTER ML — INTERS PT OF ℄ ROLL ENGINES.
(2) ALL LINEAR MEASUREMENTS IN INCHES.
(3) JET NUMBERING SUGGESTED BY MIT.



SECTION M-M
(TYPICAL RADIAL SECTION THRU ℄ YAW OR AFT PITCH ENGINES)

Fig. 6-20 CM Reaction Jet Positions.

6.4.6 CM Data

Aerodynamic reference area	129.4 square feet
Aerodynamic reference diameter	154.0 inches
Aerodynamic coefficionts	see: Tables 6-4 - 6-14

Tables 6-4 through 6-14 are aerodynamic coefficients against angle of attack for AFM - 011 command module with protuberances and canted heat shield. Moment reference center for all tables at X = 1141.25 Z = 0.0. Data is corrected for humped umbilical. Cant angle = 0.2983°.

Table 6-4
Mach = 0.0 to 0.7

α, deg.	C_M	C_N	C_A
140.2983	0.08749	0.02501	-0.83499
145.2983	0.08573	0.04745	-0.89520
150.2983	0.06104	0.04133	-0.93657
155.2983	0.04133	0.03218	-0.95207
160.2983	0.03153	0.01953	-0.97161
165.2983	0.02479	0.01271	-0.98972
170.2983	0.00059	0.02141	-0.96663
175.2983	-0.01433	0.03586	-0.98082
180.2983	-0.0212	0.01387	-0.98609

Table 6-5
Mach = 0.9

α, deg.	C_M	C_N	C_A
140.2983	0.03173	0.07901	-0.95503
145.2983	0.02379	0.07502	-1.00250
150.2983	0.02243	0.06412	-1.03725
155.2983	0.02108	0.05090	-1.07128
160.2983	0.02034	0.03474	-1.09934
165.2983	0.01977	0.02680	-1.10208
170.2983	0.00556	0.02431	-1.08228
175.2983	-0.00897	0.02472	-1.07840
180.2983	-0.02051	0.02537	-1.08315

Table 6-6

Mach 1.1

α, deg.	C_M	C_N	C_A
140.2983	-0.02176	0.15683	-1.17721
145.2983	0.00742	0.09593	-1.22972
150.2983	0.01357	0.06905	-1.25324
155.2983	0.01481	0.05055	-1.28011
160.2983	0.01645	0.03629	-1.34065
165.2983	0.01782	0.02443	-1.34452
170.2983	0.02005	0.01323	-1.30433
175.2983	0.01971	0.03261	-1.29187
180.2983	0.02146	0.03326	-1.29519

Table 6-7

Mach = 1.2

α, deg.	C_M	C_N	C_A
140.2983	-0.03116	0.16425	-1.17170
145.2983	0.00380	0.09655	-1.21555
150.2983	0.01067	0.07134	-1.23571
155.2983	0.01184	0.05596	-1.26145
160.2983	0.01174	0.04044	-1.29859
165.2983	0.00986	0.02607	-1.29746
170.2983	0.00587	0.01107	-1.29506
175.2983	0.00594	-0.00191	-1.29702
180.2983	-0.01446	0.00724	-1.30006

Table 6-8
Mach = 1.35

α, deg.	C_M	C_N	C_A
140.2983	-0.07148	0.21600	-1.23037
145.2983	-0.03401	0.16110	-1.32228
150.2983	-0.00553	0.10277	-1.38552
155.2983	0.00609	0.07434	-1.40863
160.2983	0.00464	0.05252	-1.41450
165.2983	0.00194	0.03311	-1.40169
170.2983	0.00269	0.02259	-1.41878
175.2983	-0.00249	0.01135	-1.41122
180.2983	-0.01222	0.01070	-1.40407

Table 6-9
Mach = 1.65

α, deg.	C_M	C_N	C_A
140.2983	-0.06894	0.20800	-1.18307
145.2983	-0.04138	0.16128	-1.29723
150.2983	-0.01231	0.11919	-1.37650
155.2983	-0.00257	0.07717	-1.43980
160.2983	0.00210	0.05079	-1.44975
165.2983	0.00276	0.03274	-1.43932
170.2983	-0.00138	0.02352	-1.46834
175.2983	-0.01570	0.02282	-1.42673
180.2983	-0.01858	0.01157	-1.42808

Table 6-10
Mach 2.0

α, deg.	C_M	C_N	C_A
140.2983	-0.07090	0.20415	-1.13656
145.2983	-0.04530	0.17387	-1.25360
150.2983	-0.01981	0.11019	-1.34536
155.2983	-0.00297	0.07072	-1.42042
160.2983	-0.00062	0.05738	-1.46651
165.2983	0.00102	0.03773	-1.46861
170.2983	-0.00136	0.02314	-1.49600
175.2983	-0.00704	0.00839	-1.49685
180.2983	-0.01661	0.01021	-1.49707

Table 6-11
Mach 2.4

α, deg.	C_M	C_N	C_A
140.2983	-0.06251	0.20165	-1.09637
145.2983	-0.04164	0.17125	-1.21004
150.2983	-0.02953	0.13041	-1.30206
155.2983	-0.01486	0.09484	-1.38203
160.2983	-0.00444	0.06450	-1.44144
165.2983	0.00210	0.03828	-1.46888
170.2983	-0.00334	0.04577	-1.49040
175.2983	0.00620	0.00056	-1.49870
180.2983	0.00631	-0.01275	-1.48995

Table 6-12

Mach = 3.0

α, deg.	C_M	C_N	C_A
135.2983	-0.07872	0.21582	-0.92269
140.2983	-0.05507	0.17414	-1.04442
145.2983	-0.03723	0.14723	-1.16168
150.2983	-0.02079	0.11646	-1.25852
155.2983	-0.00981	0.08610	-1.32797
160.2983	-0.00036	0.05776	-1.39062
165.2983	0.00405	0.03250	-1.44169
170.2983	-0.00005	0.01167	-1.46188
175.2983	0.01114	-0.01451	-1.47914
180.2983	0.00134	-0.01972	-1.48292

Table 6-13

Mach = 4.0

α, deg.	C_M	C_N	C_A
140.2983	-0.04565	0.16967	-0.98660
145.2983	-0.03278	0.14301	-1.09316
150.2983	-0.02235	0.11650	-1.19072
155.2983	-0.01159	0.08916	-1.27548
160.2983	-0.00553	0.06552	-1.34146
165.2983	-0.00263	0.04393	-1.39655
170.2983	-0.00073	0.02504	-1.43385
175.2983	-0.00062	0.00753	-1.45426
180.2983	-0.00599	-0.00760	-1.45998

Table 6-14

Mach 6 to 25

α, deg.	C_M	C_N	C_A
110.2983	-0.21100	0.36800	-0.20000
115.2983	-0.17400	0.33000	-0.34000
120.2983	-0.13900	0.29300	-0.49000
125.2983	-0.10800	0.25800	-0.61000
130.2983	-0.08200	0.22500	-0.73000
135.2983	-0.05900	0.19300	-0.86000
140.2983	-0.04189	0.16621	-0.97978
145.2983	-0.02859	0.13952	-1.08325
150.2983	-0.01988	0.11646	-1.17693
155.2983	-0.01199	0.09211	-1.26749
160.2983	-0.00770	0.07055	-1.34495
165.2983	-0.00354	0.04845	-1.41400
170.2983	-0.00123	0.02666	-1.46141
175.2983	-0.00023	0.00770	-1.48436
180.2983	0.00413	-0.00775	-1.48992
185.2983	0.00000	-0.01400	-1.47000
190.2983	-0.00200	-0.01500	-1.45000

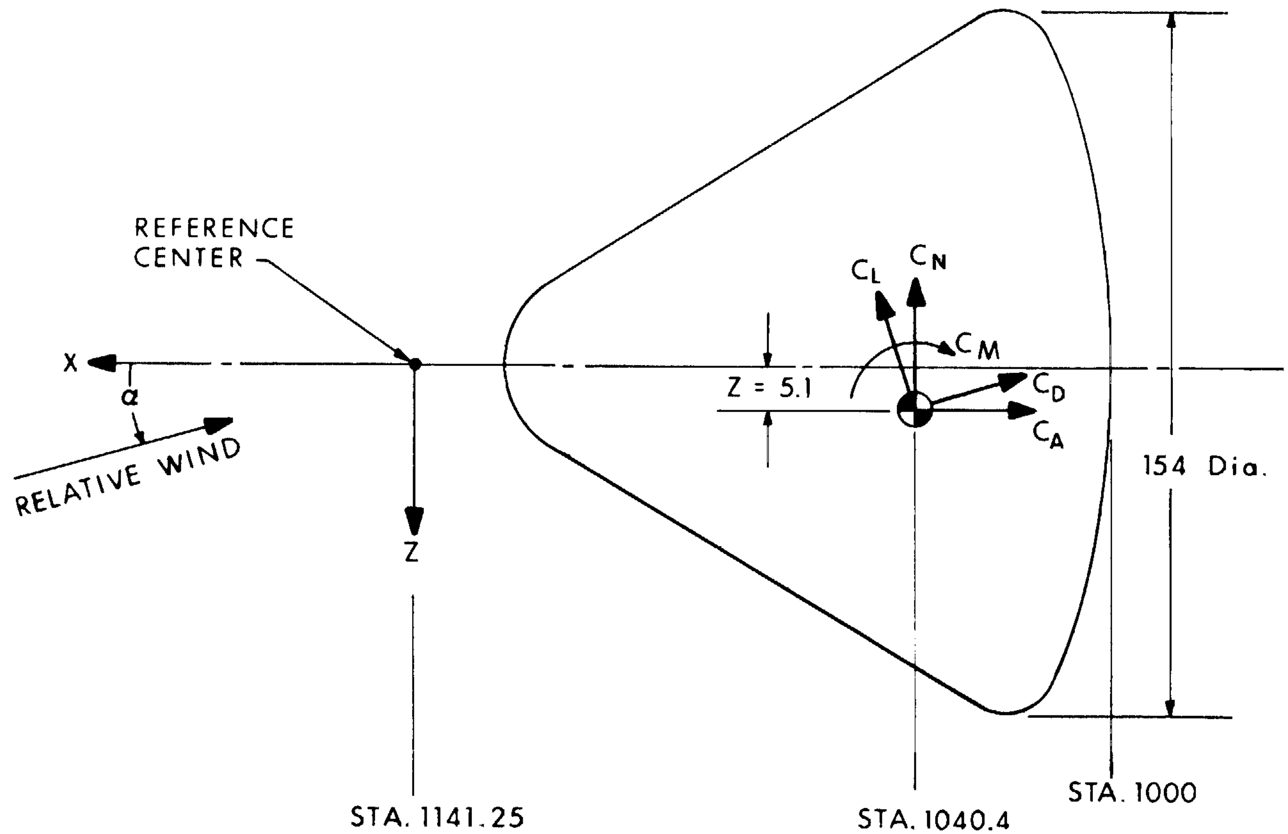


Fig. 6-21 CM Axis System and Reference Center of Gravity

6.5 Physical constants

6.5.1 Geophysical constants

	Symbol	Value
Earth's gravitation constant	MUE	$3.986\ 032\ 233 \times 10^{14}$ meters^3/sec^2
Gravity potential harmonic coeff.	J	1.62345×10^{-3}
	H	-0.575×10^{-5}
	D	0.7875×10^{-5}
Earth's mean equatorial radius	RE	$6.378\ 165 \times 10^{6}$ meters
Earth's sidereal rate	WIE	$7.292\ 115\ 05 \times 10^{-5}$ radians/sec
Reference ellipsoid		Fischer, 1960

6.5.2 Conversion Factors

	Multiply by
International feet to meters	0.304 8
Pounds to newtons	4.448 221 530
Slugs to kilograms	14.593 902 680
Nautical miles to kilometers	1.852
Statute miles to kilometers	1.609 344 000
Slugs to pounds (g)	32.174 048 000 ft/s/s

[redacted]

SECTION 7

G & N ERROR ANALYSIS

This section provides up-to-date results on G&N Error Analysis. Two sets of error tables are given in this chapter.

The first set (Tables 7-A-1 through 7-A-15) were computed for the case where C.M. IMU component error uncertainties were equal to Block II specifications (1σ). Table 7-A-1 is a summary table that gives RSS uncertainties at each major event for the no update and the two update cases. The Block II specifications for IMU uncertainties are given below the summary table. Tables 7-A-2 through 7-A-15 break down each line of the summary table into the contributions of each IMU component uncertainty term. The particular IMU uncertainties with the most significant effects are denoted by asterisks.

The second set (Tables 7-B-1 through 7-B-15) were computed for the case where C. M. IMU component error uncertainties were equal to latest IMU System No. 017 measurement data. As was the case for the first set, the first table is a summary table and the other tables are detailed breakdown tables. The latest System 017 data are given below the summary table.

On the basis of the above data the following key uncertainties are estimated for the two sets of IMU component uncertainties considered. Set A are the Block II specification uncertainties, and Set B are the latest System 017 measured uncertainties.

	with no navigational update		with perfect update just prior to SPS 1st Burn ignition		with perfect update just prior to SPS 2nd Burn ignition	
IMU Uncertainties* →	Set A	Set B	Set A	Set B	Set A	Set B
Entry γ (one sigma)	0.095	0.088	0.031	0.023	0.011	0.007 deg
Entry V (one sigma)	1.7	0.9	1.1	0.6	1.0	0.7 ft/sec
CEP at Pacific Recovery Point	13.1	11.6	4.3	3.0	1.3	1.1 n. mile

*See Note 9 (p. 7-3) for definition of uncertainty in Entry γ and V.

[redacted]

The use of either set of values for IMU uncertainties assumes that the AGC will provide compensation for the measured average values of the following IMU errors: accelerometer bias errors and scale factor errors, gyro bias drift and gyro acceleration sensitive drift errors. Since the average IMU component errors will be compensated for during the pre-launch period and the flight itself, it is the unpredictable deviations from the measured average errors that result in the indication uncertainties during flight. It should be mentioned that the error data given for System 017 uncertainties for accelerometer non-linearity and for gyro acceleration squared sensitive drift were not obtained from IMU test measurements but rather from general tests made of IMU components of identical design. Also, the errors listed for accelerometer input axis misalignments represent the average measured alignment errors, since there will be no AGC compensation for these errors.

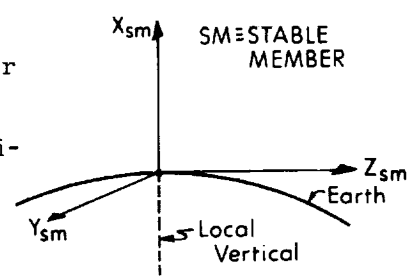
The error tables described above were computed for three update conditions. These were:

1) No navigational ($\bar{R}$, $\bar{V}$) update at any point in the flight.
2) Perfect navigational update just prior to SPS 1st Burn ignition.
3) Perfect navigational update just prior to SPS 2nd Burn ignition.

The effects of Tracking data uncertainties on navigational update were not included in the present error studies for lack of time. They will be included in the next revision.

The following comments explain the terminology, method of analysis and the basic assumptions used.

1) The IMU Stable Member axes are aligned prior to launch relative to local vertical axes as indicated in sketch. X_{SM} is up along local vertical at instant of launch, while Z_{SM} is along local horizontal pointed down-range at an azimuth of 105 degrees.



2) The data in the error tables are given relative to local vertical axes (altitude, track, range) at the particular event designated.

3) Only the significant error figures have been listed in the error tables.

4) No realignment of the Stable Member was assumed.

5) Accelerometer bias errors affect indication errors in two ways. First, they affect the initial pre-launch alignment of the Stable Member. Second, they affect the in-flight computation of position and velocity. The two effects are summed in the tables, since the accelerometer bias error prior to launch is assumed to be correlated with the error during flight.

6) Accelerometer inputs to the AGC are not used during the free-fall phases of the trajectory.

7) The item "Uncorrelated SM Alignment Errors" in the error tables do not include the alignment errors due to accelerometer bias errors or to gyro bias and acceleration sensitive drift. Since, for these particular IMU errors, the pre-launch error is assumed correlated with the in-flight error, the two effects are algebraically summed in the tables. Note that the azimuth alignment error is affected primarily by the Z gyro bias drift effect on the gyro-compassing loop during pre-launch alignment. For example, for Set B of IMU uncertainties, the Z gyro bias drift uncertainty is 1.6 meru. The resulting azimuth alignment uncertainty is 1.76 mr., while the RSS azimuth alignment uncertainty due to all IMU uncertainties is about 2.0 mr.

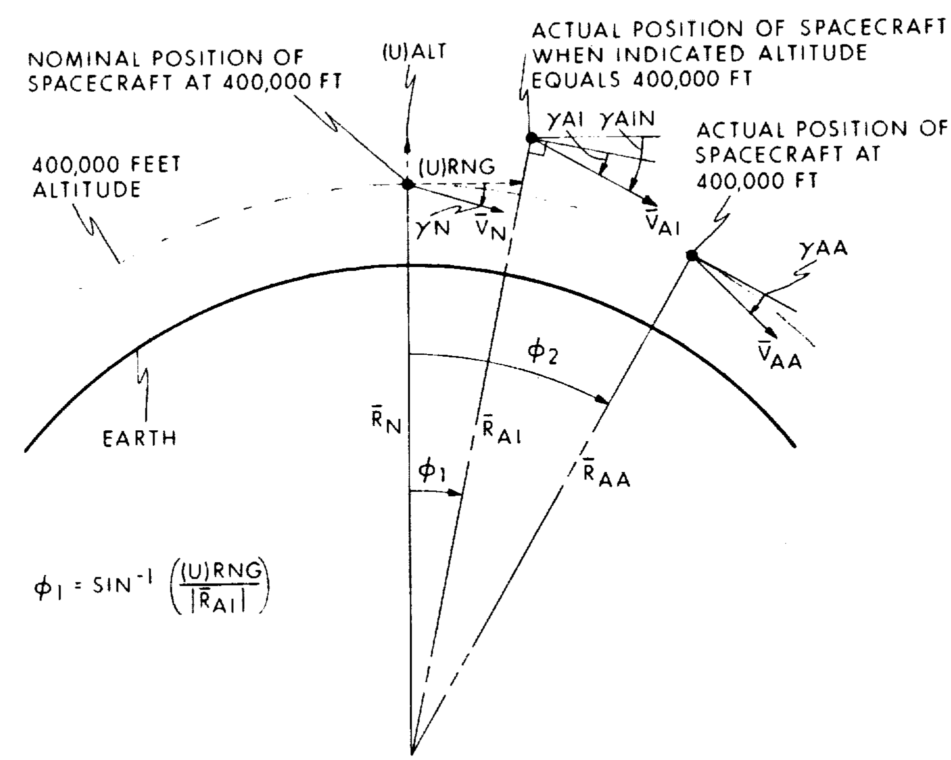
The uncorrelated SM alignment error about azimuth X_I is caused primarily by misalignment of the Z gyro input axis relative to the Z stable member axis.

8) The position and velocity errors given in the tables were computed as follows. Approximate error equations were derived for the effect of each IMU component error on indication of trajectory position and velocity. The basic assumptions were: 1. that the errors were small relative to the parameters being measured, and 2. that the IMU component errors were statistically independent of each other. The equations took into account the effect of the platform error on the gravity vector computation. The error equations required as inputs acceleration and position vectors. These were generated at each time step by a reference trajectory. At important times, such as SIVB cutoff, detailed printouts were made giving the position and velocity errors due to each IMU error together with the RSS of these errors relative to desired coordinate axes.

9) The uncertainty in entry γ (flight path angle) is defined as the uncertainty in the actual flight path angle, γ_{AA}, (see Fig. 7.1), as compared with the nominal flight path angle, γ_N. Note that γ_{AA} is measured with respect to the particular local horizontal axis at the S/C when the spacecraft reaches 400,000 ft. Similarly, the uncertainty in entry V is the uncertainty in V_{AA} as compared with V_N. Since the guidance equations steer to force $\gamma_{AA} = \gamma_N$ and $V_{AA} = V_N$, the uncertainties in γ_{AA} and V_{AA} equal the errors in γ_{AA} and V_{AA}, respectively. It should be noted that in previous reports the uncertainty in entry γ was computed on the basis of the equation for $(U)\gamma_{AIN}$ rather than for $(U)\gamma_{AA}$ as was done for this report. For the no-update case

[redacted]

with Set A IMU uncertainties the following flight path angle uncertainties were computed: (U)γ_{AIN} = 0.163 deg., (U)γ_{AI} = 0.057 deg., (U)γ_{AA} = 0.095 deg. (as given in table on pp. 7-1). Please also note that altitude rate uncertainties in all error tables in this report were computed on the basis of the equation for (U)$\dot{\text{Alt}}_{AIN}$ rather than for (U)$\dot{\text{Alt}}_{AA}$. Subsequent reports will present data for (U)γ_{AA} and (U)$\dot{\text{Alt}}_{AA}$ in more detail.



Flight Path Angle and Velocity Uncertainty Equations

(U)$\gamma_{AIN} = \gamma_{AIN} - \gamma_N$

(U)$\gamma_{AI} = \gamma_{AI} - \gamma_N$ (U)$V_{AI} = V_{AI} - V_N$

(U)$\gamma_{AA} = \gamma_{AA} - \gamma_N$ (U)$V_{AA} = V_{AA} - V_N$

Altitude Rate Uncertainty Equations

(U)$\dot{\text{Alt}}_{AIN} = V_{AI} \sin \gamma_{AIN} - V_N \sin \gamma_N \simeq (\bar{V}_{AI} - \bar{V}_N) \cdot \bar{R}_N / R_N$

(U)$\dot{\text{Alt}}_{AI} = V_{AI} \sin \gamma_{AI} - V_N \sin \gamma_N$

(U)$\dot{\text{Alt}}_{AA} = V_{AA} \sin \gamma_{AA} - V_N \sin \gamma_N$

Note that γ_{AIN} is measured with respect to the same nominal horizontal axis as γ_N, while γ_{AI} and γ_{AA} are measured with respect to their particular local horizontal axes.

Fig. 7-1 Flight Path Angles at Reentry

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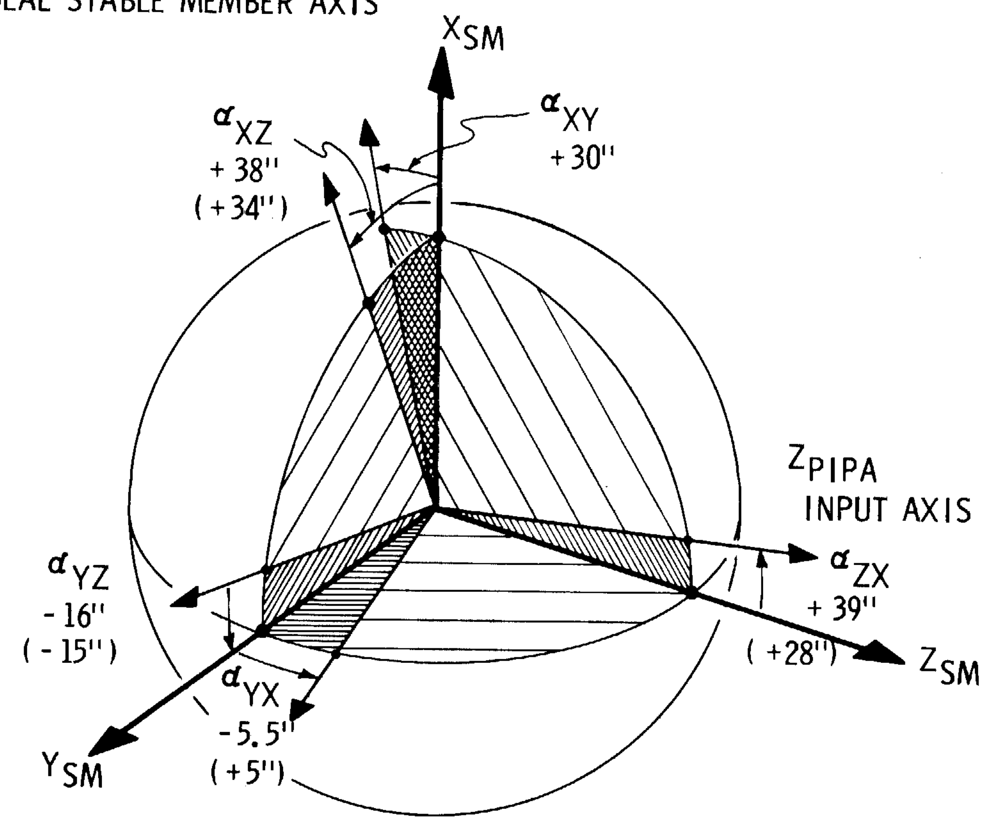
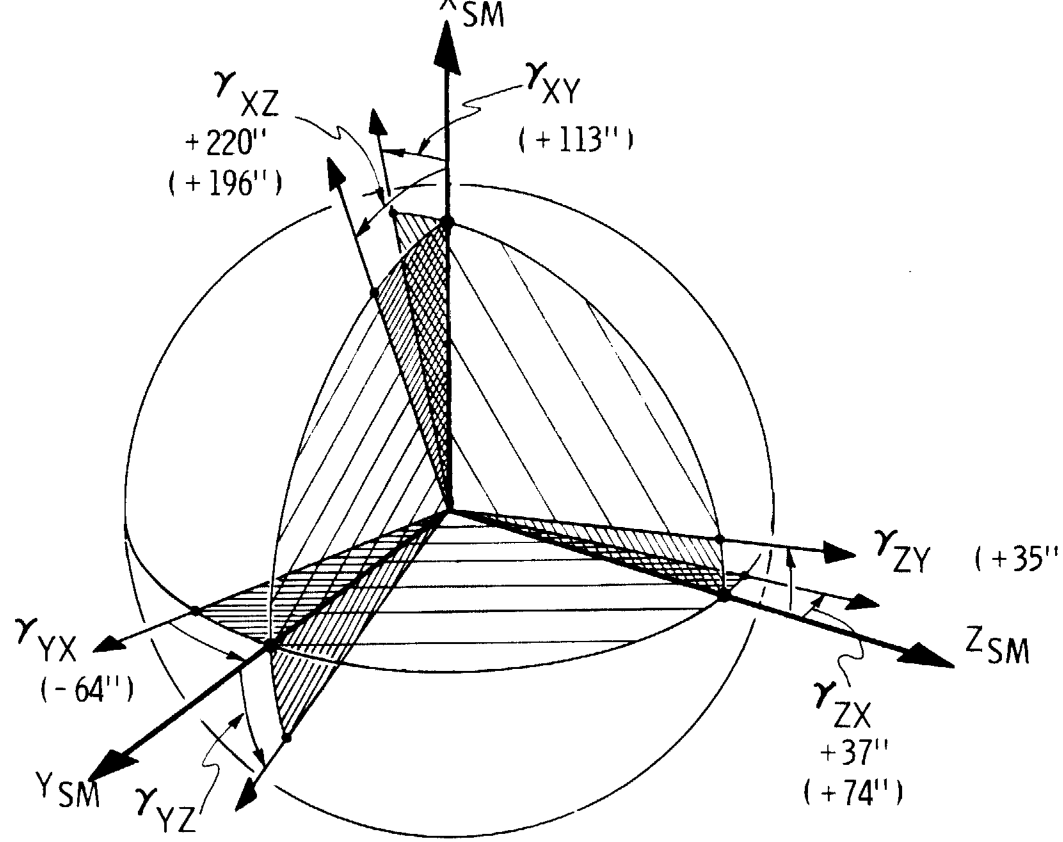
PIPA INPUT AXIS ALIGNMENT WITH RESPECT TO IDEAL STABLE MEMBER AXIS G&N 17



( ) POST WORKMANSHIP VIBRATION MEASUREMENT

STABLE MEMBER	X	Y	Z
X PIPA	+ IA	+ PRA	+ OA
Y PIPA	+ PRA	+ IA	- OA
Z PIPA	+ OA	- PRA	+ IA

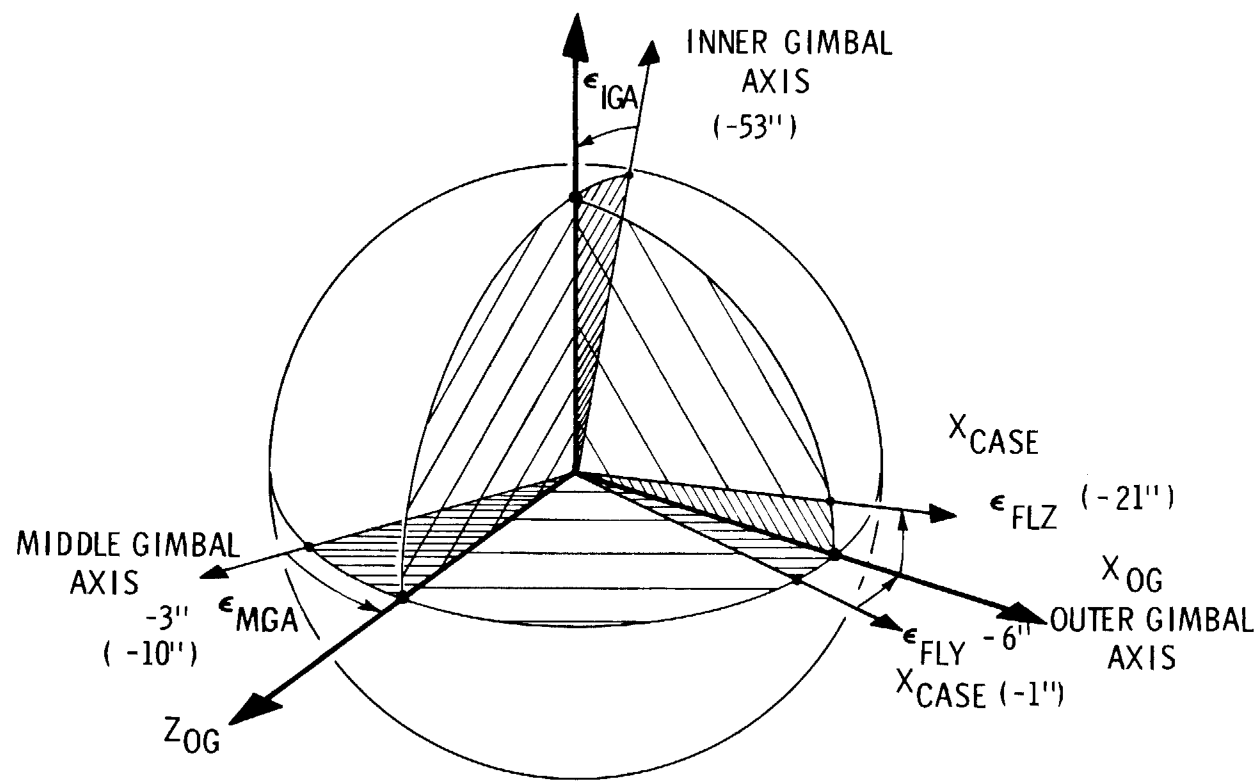
IRIG INPUT AXIS ALIGNMENT
WITH RESPECT TO STABLE MEMBER AXIS
G&N 17



STABLE MEMBER	X	Y	Z
X IRIG	+ IA	- SRA	+ OA
Y IRIG	+ OA	+ IA	- SRA
Z IRIG	+ OA	+ SRA	+ IA

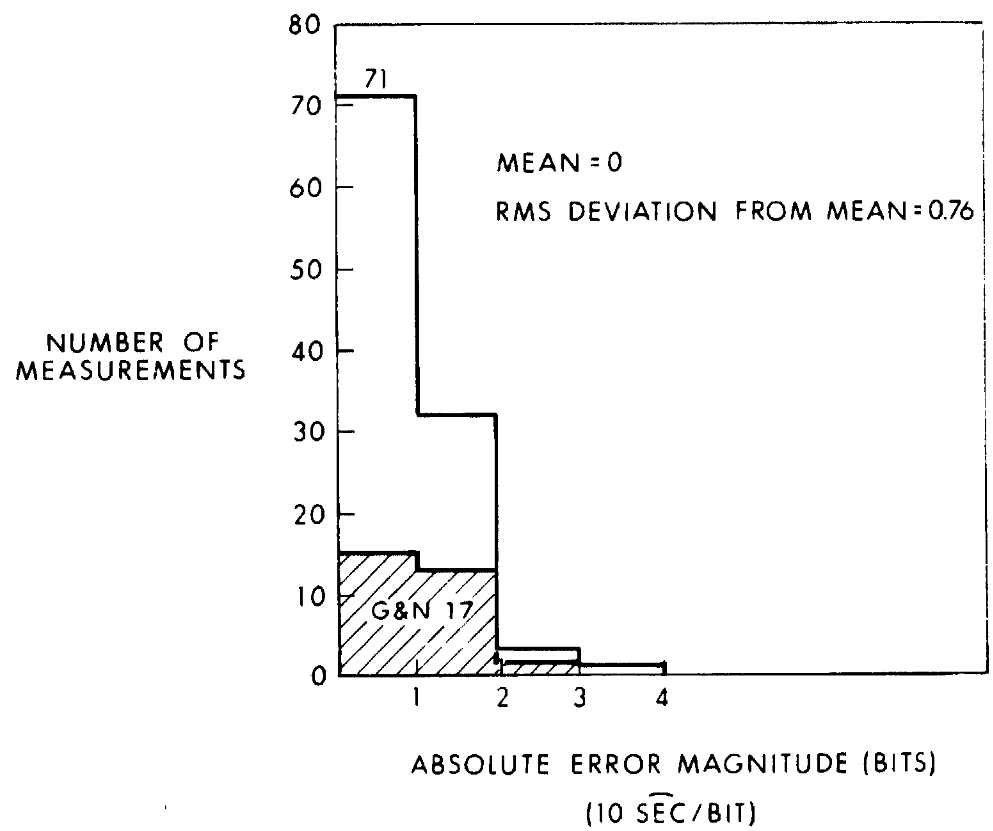
( ) POST WORKMANSHIP VIBRATION MEASUREMENT

GIMBAL AXIS ORTHOGONALITY
OUTER GIMBAL ALIGNMENT WITH RESPECT
TO CASE MOUNTING ALIGNMENT
G&N 17

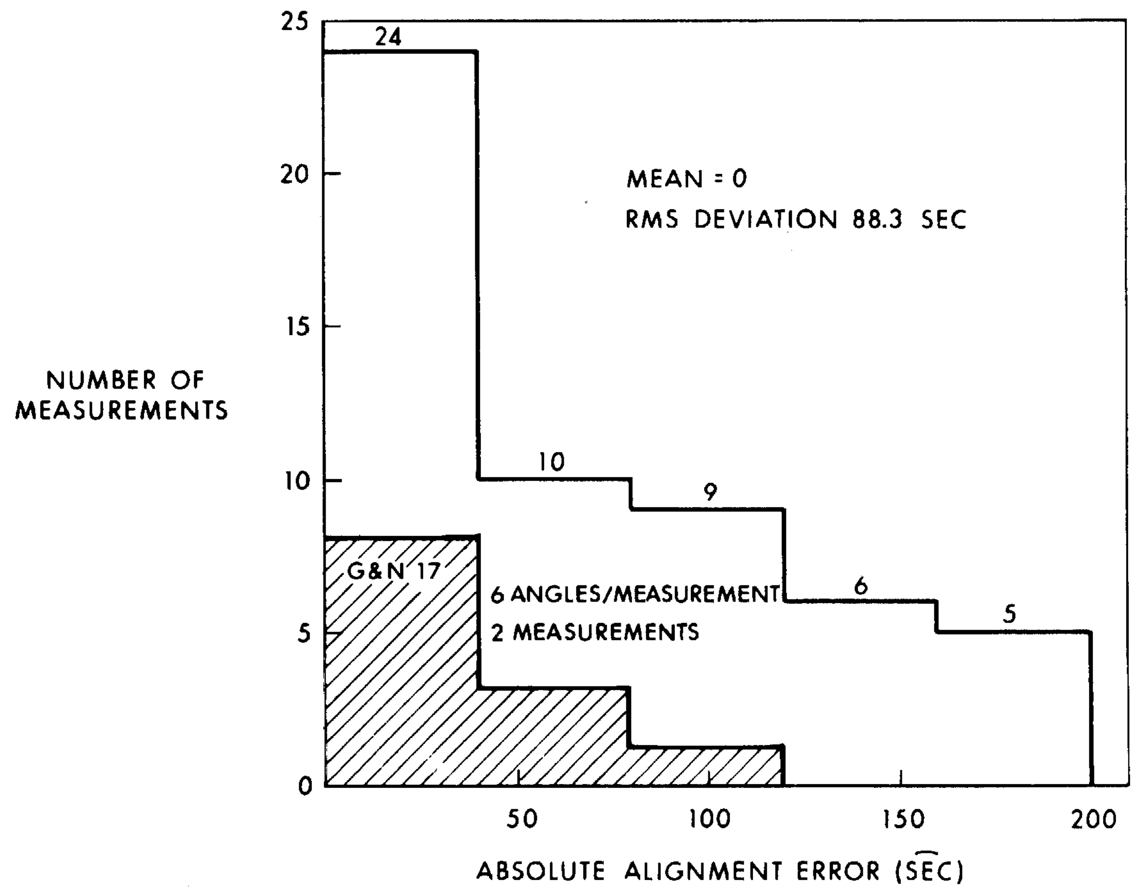


( ) POST WORKMANSHIP
VIBRATION MEASUREMENT

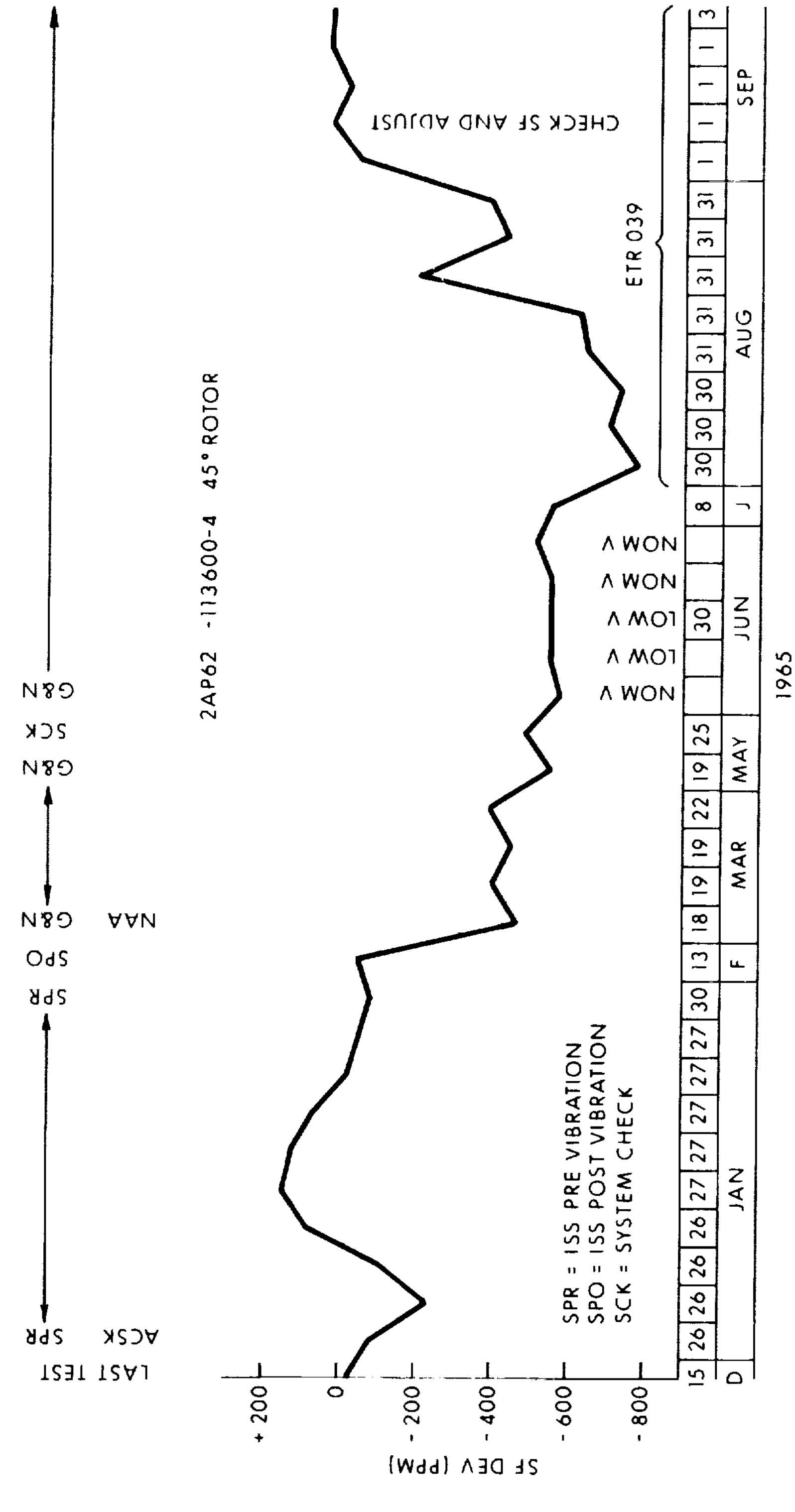
1. STAR-LANDMARK ANGLE MEASUREMENT
(RESULTS OF 16 TESTS ON 7 SYSTEMS)



2. IMU ALIGNMENT
(54 MEASUREMENTS, 6 BLOCK I SYSTEMS)



IMU 17 △SCALE FACTOR X PIP



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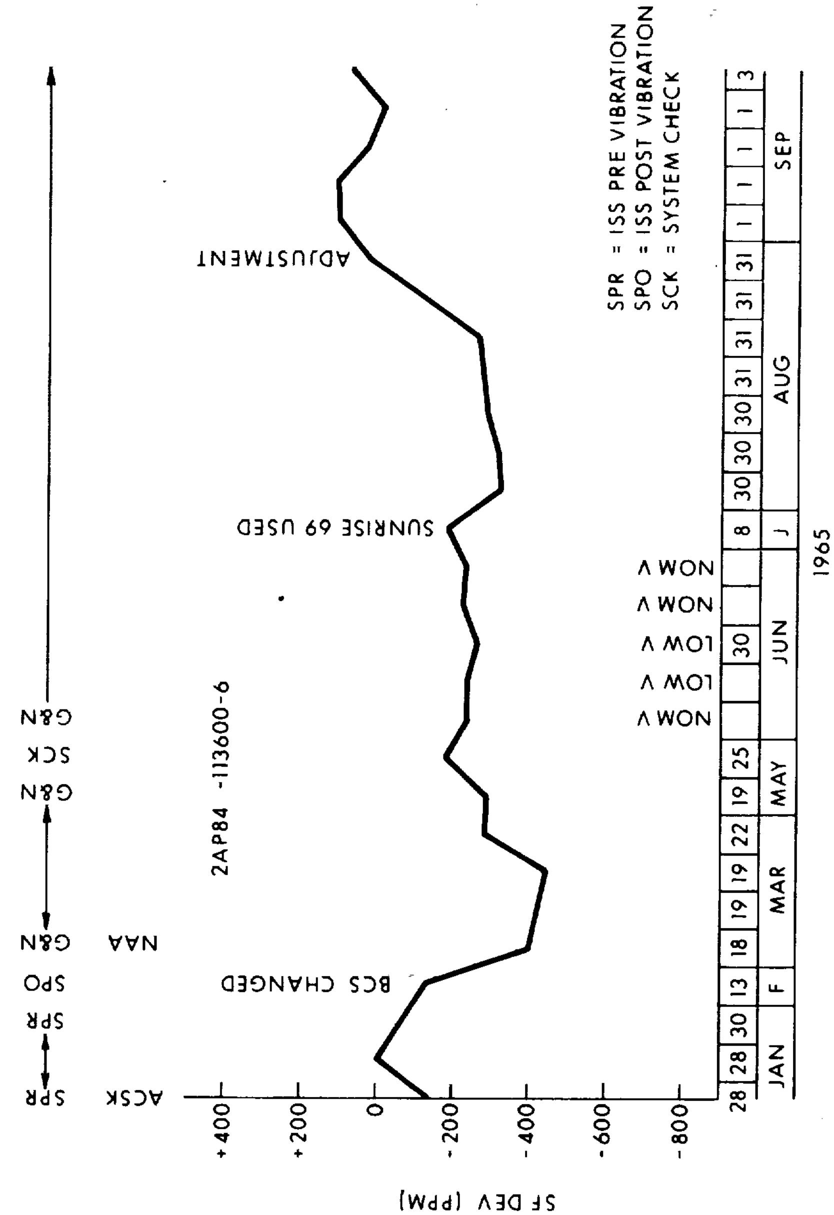
IMU 17 Δ SCALE FACTOR Y PIP



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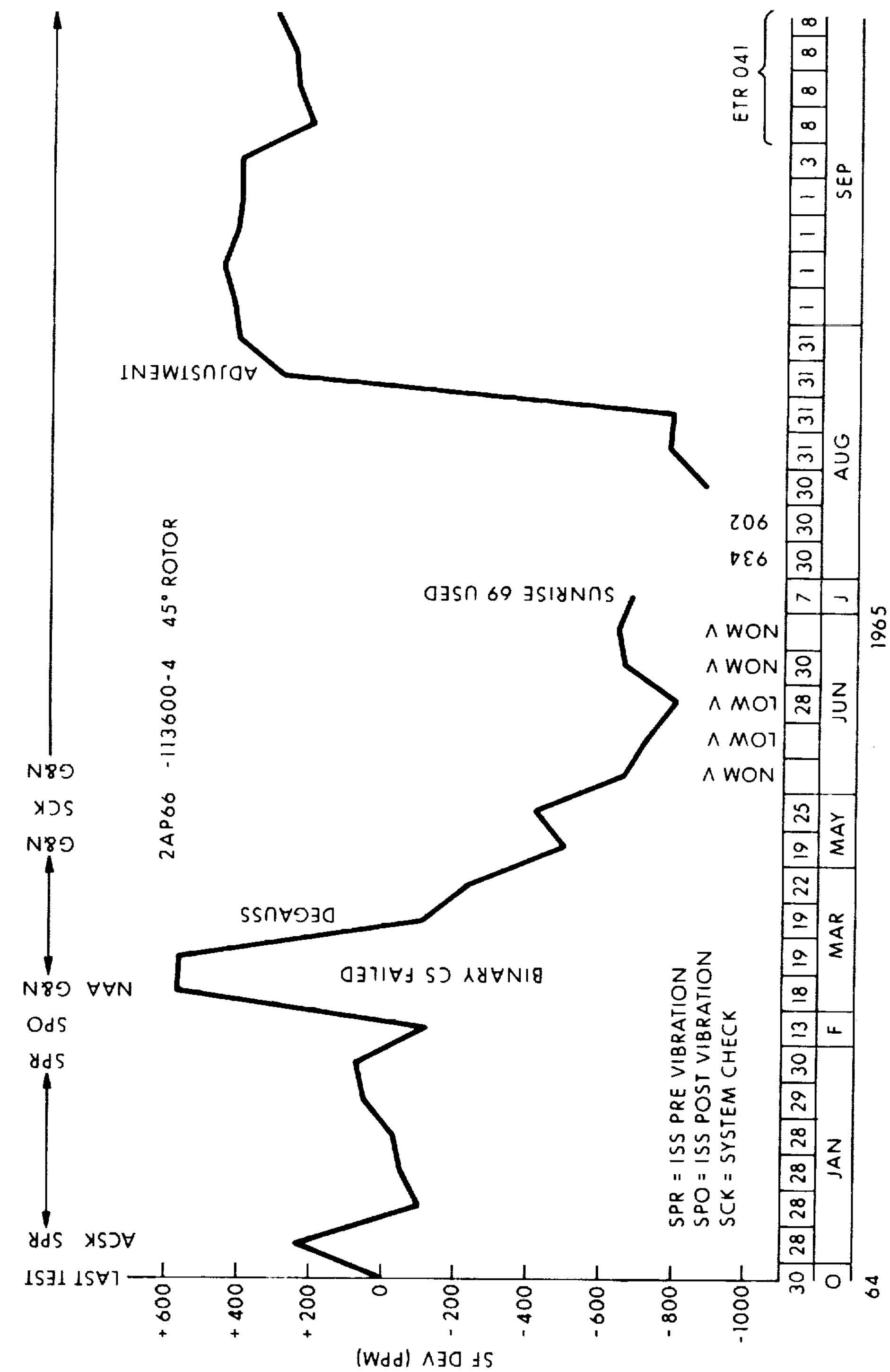
IMU 17 △ SCALE FACTOR Z PIP



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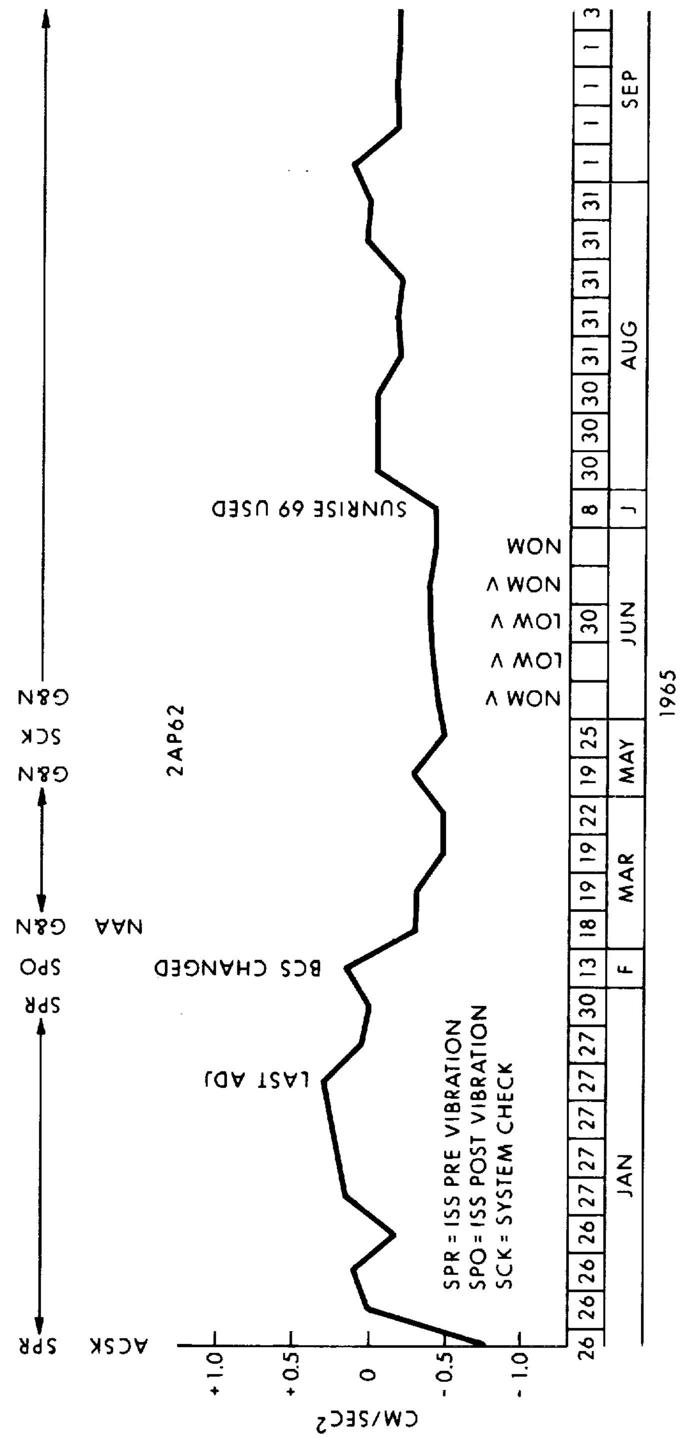
IMU 17 19 BIAS X PIP



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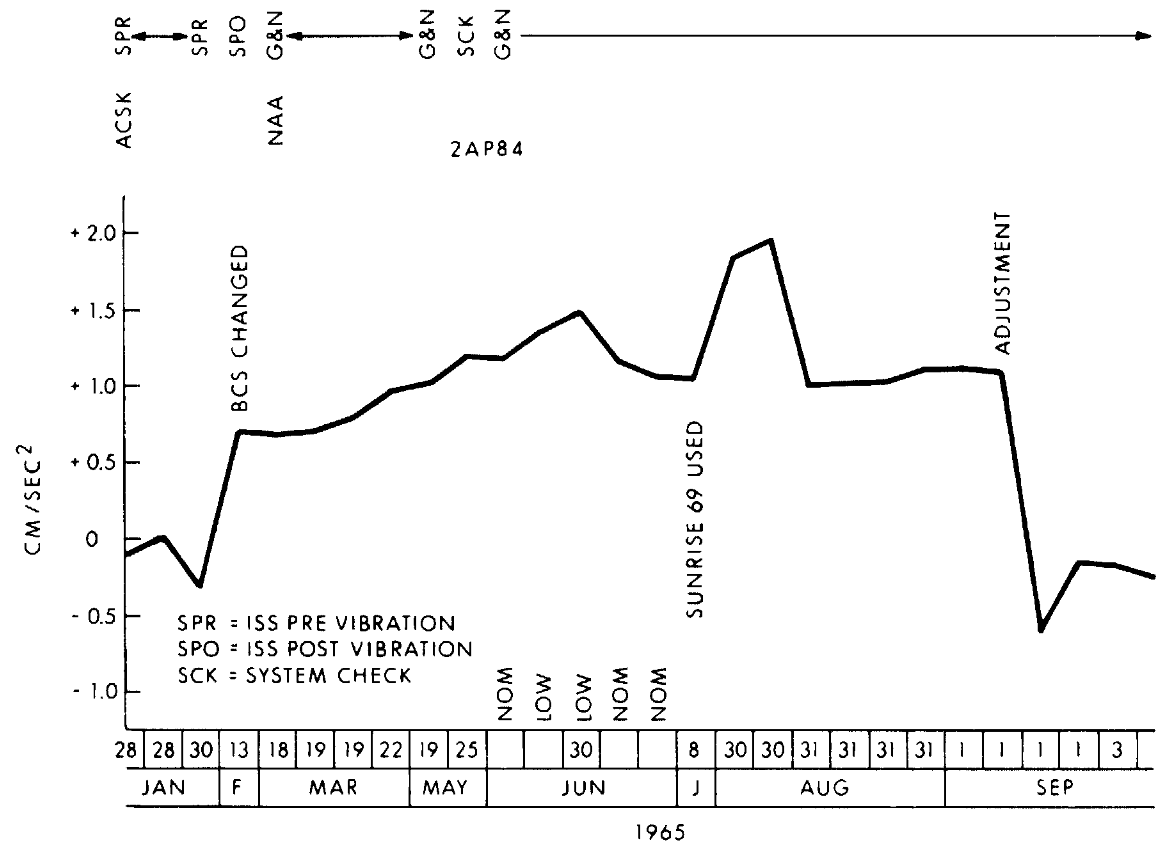
IMU 17 19 BIAS Y PIP



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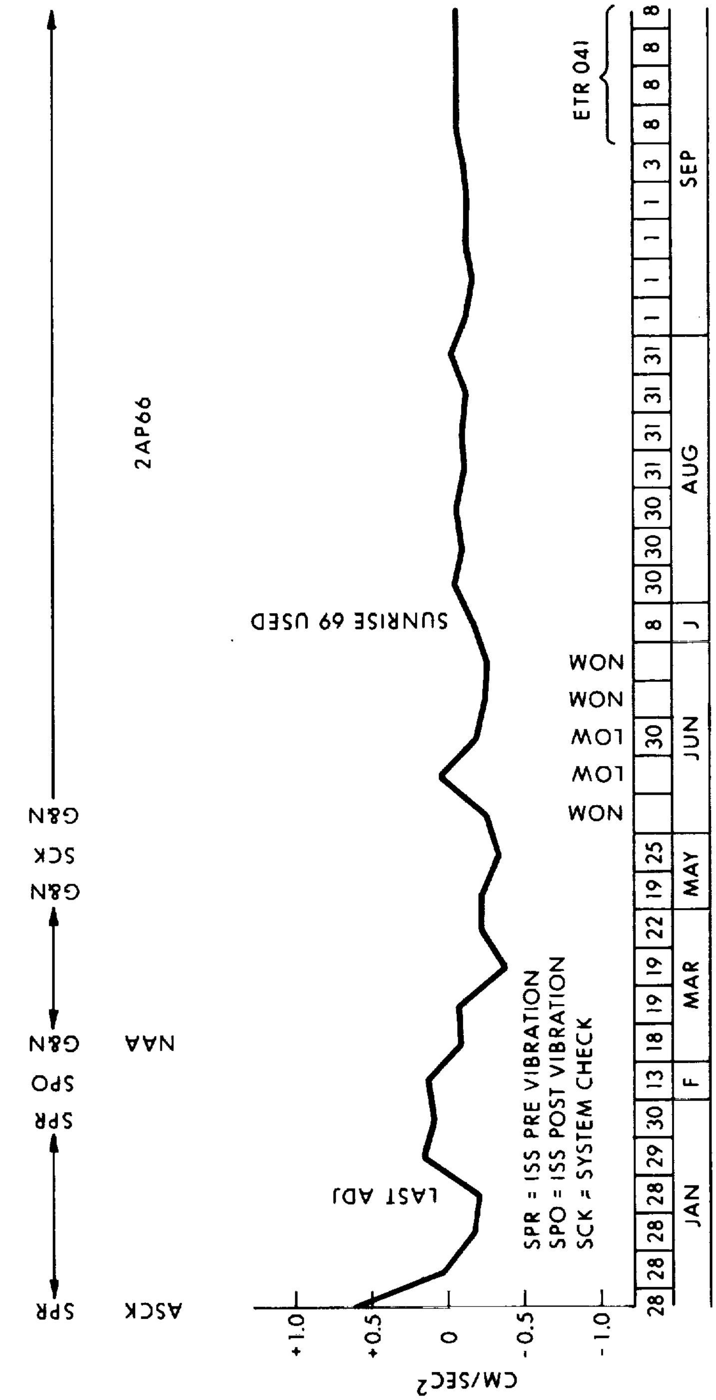
IMU 17 19 BIAS Z PIP



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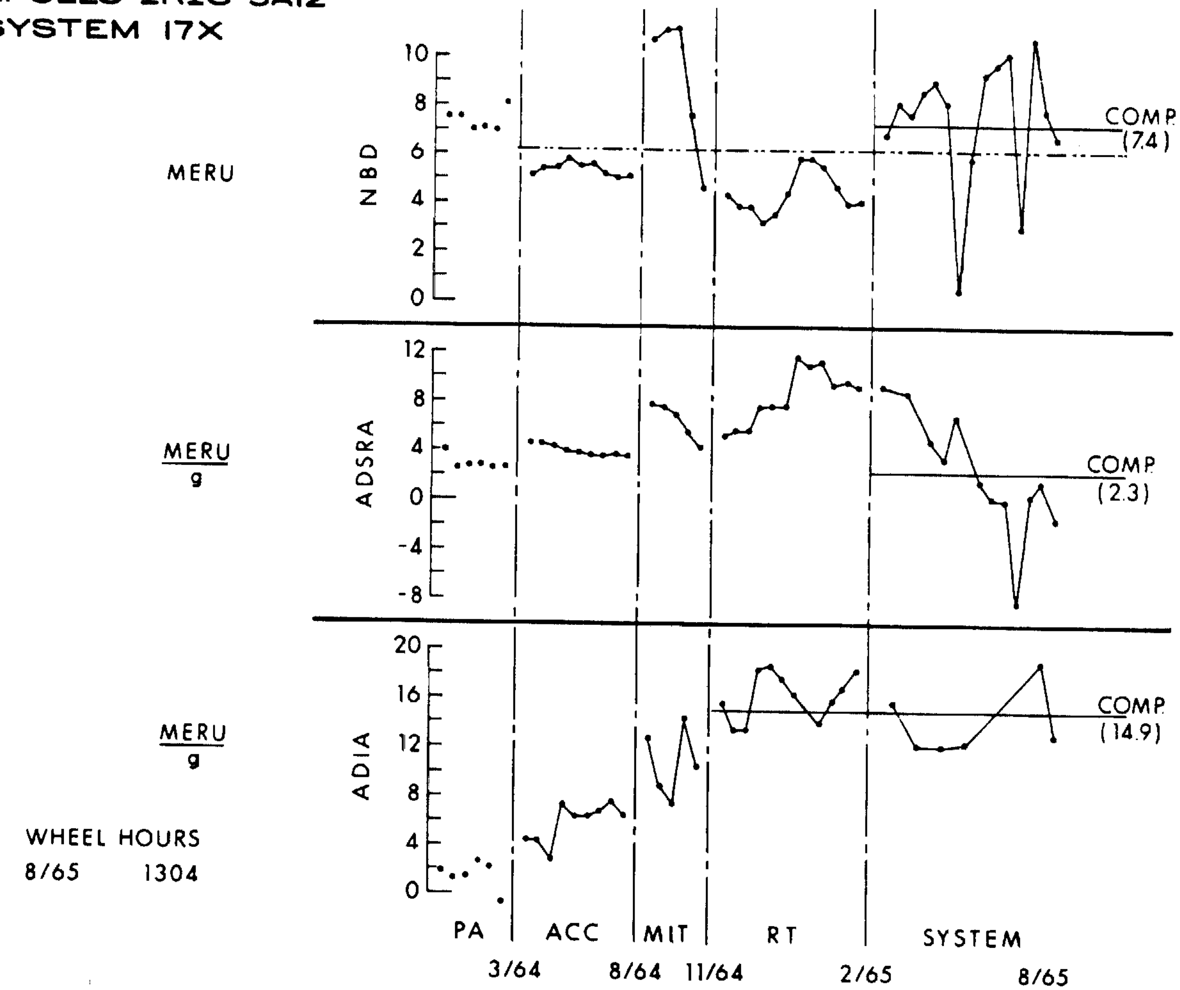
APOLLO IRIG 3A12
SYSTEM 17X



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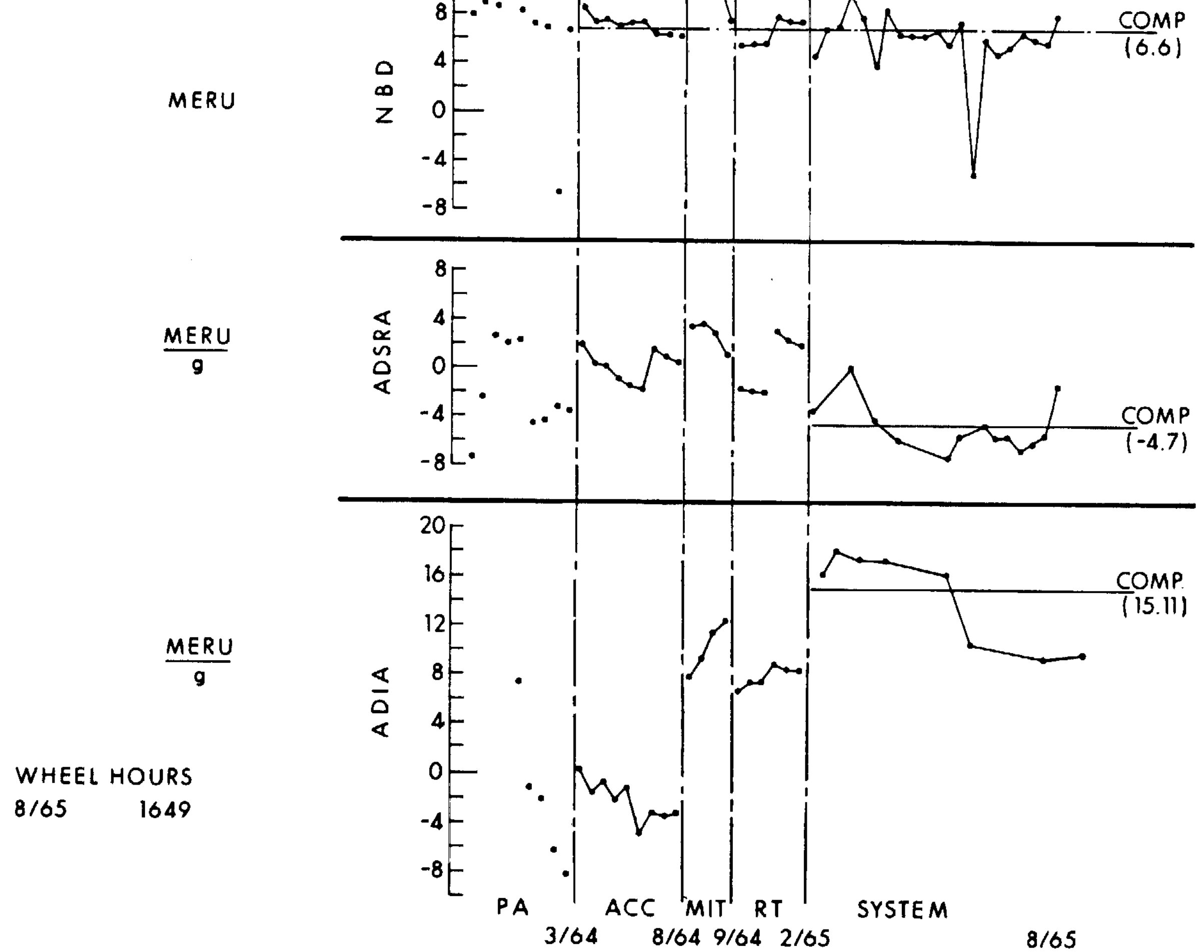
APOLLO IRIG 3A10
SYSTEM 17Y



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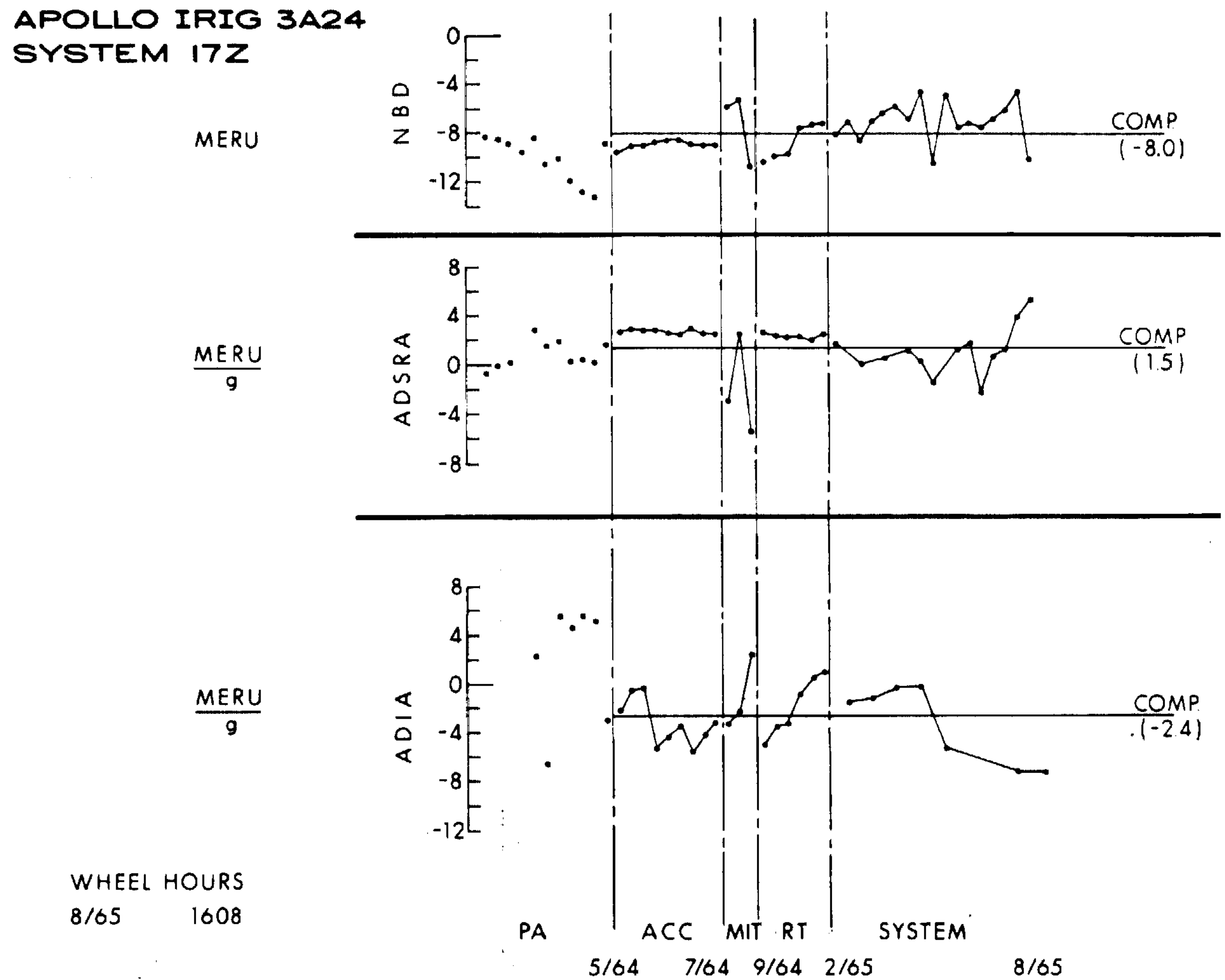

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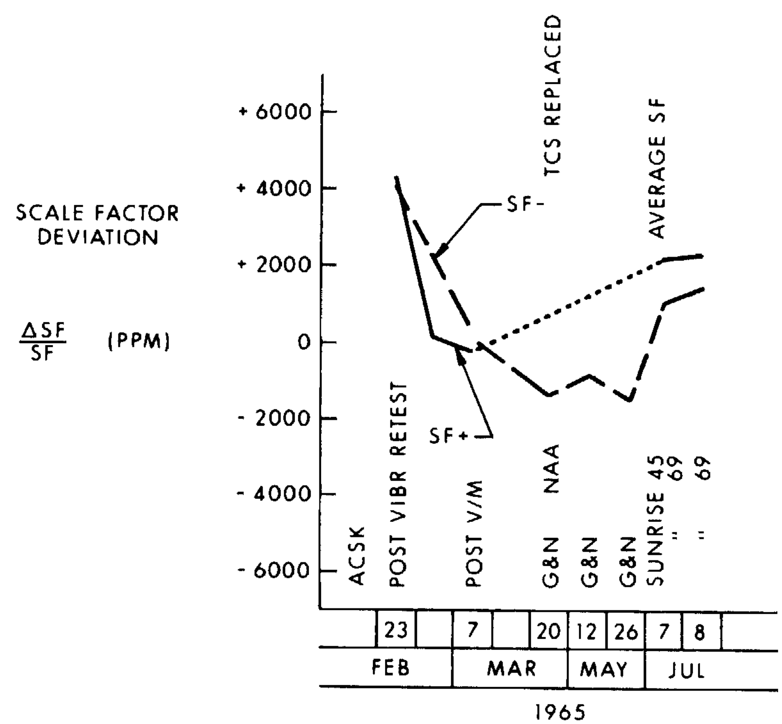
IRIG SCALE FACTOR IMU 17 X IRIG 3A-12



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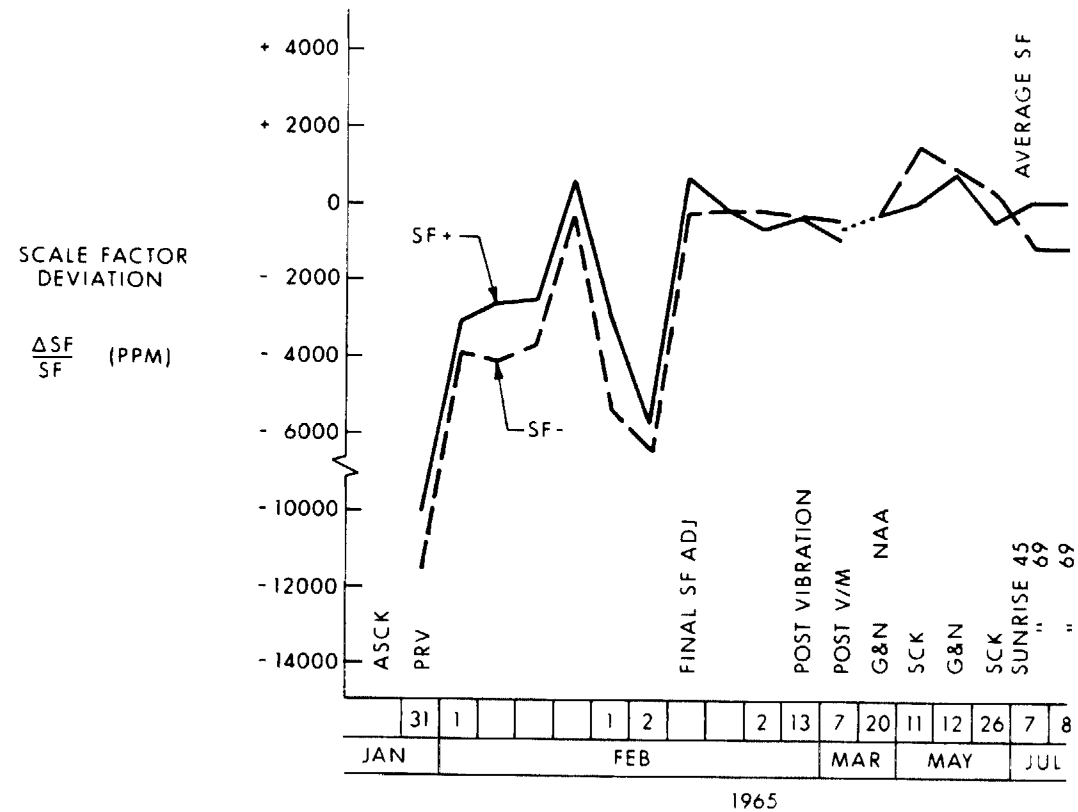
IRIG SCALE FACTOR IMU 17 Y IRIG 5A-10



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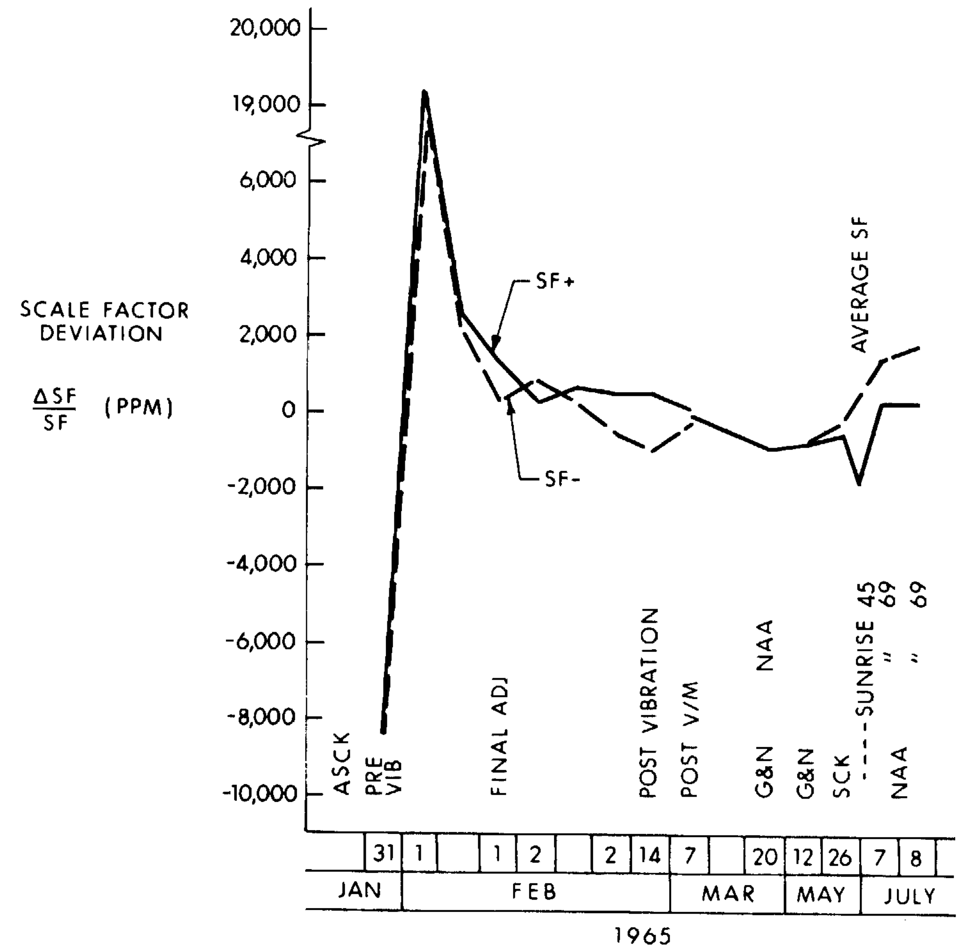
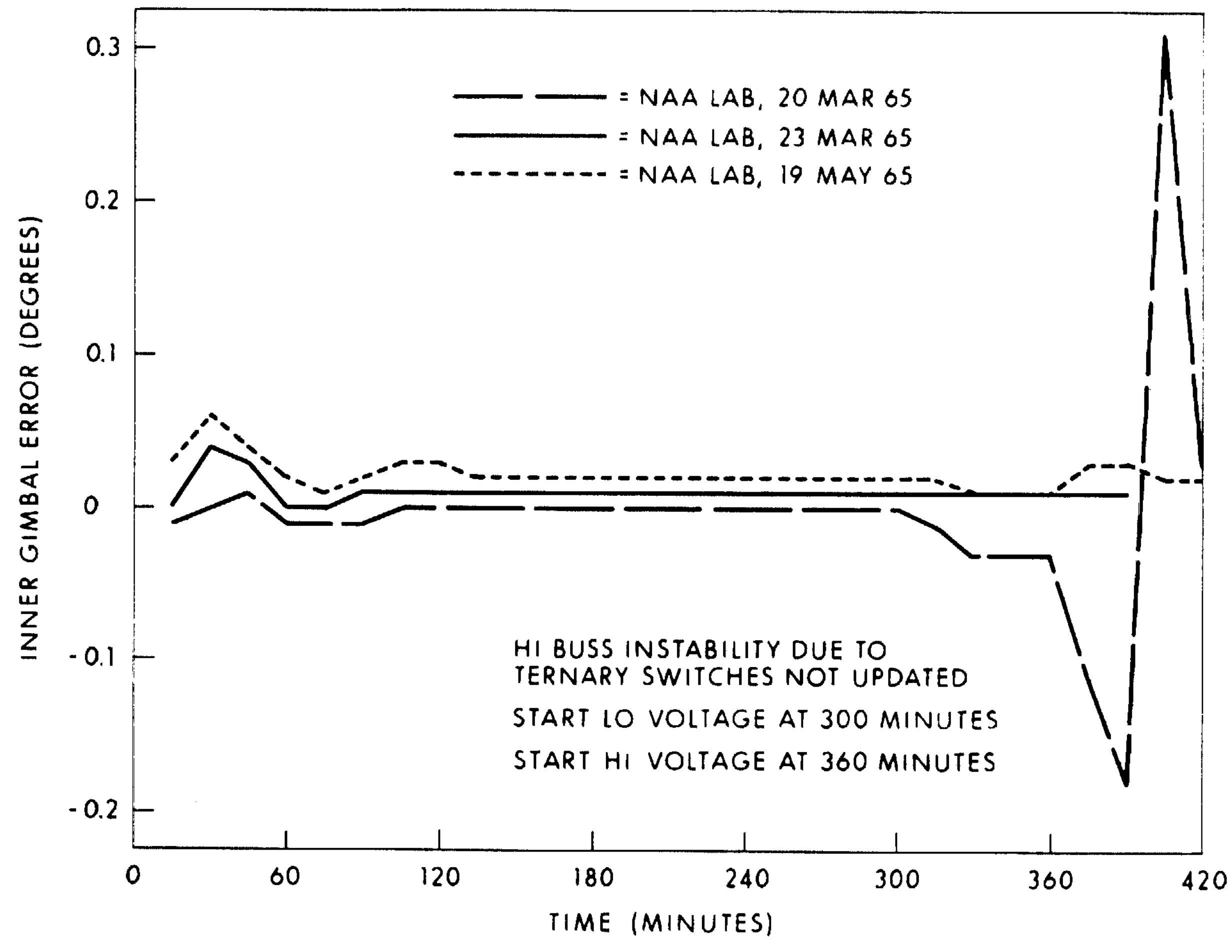
IRIG SCALE FACTOR IMU 17 Z AXIS 3A-24



[redacted]

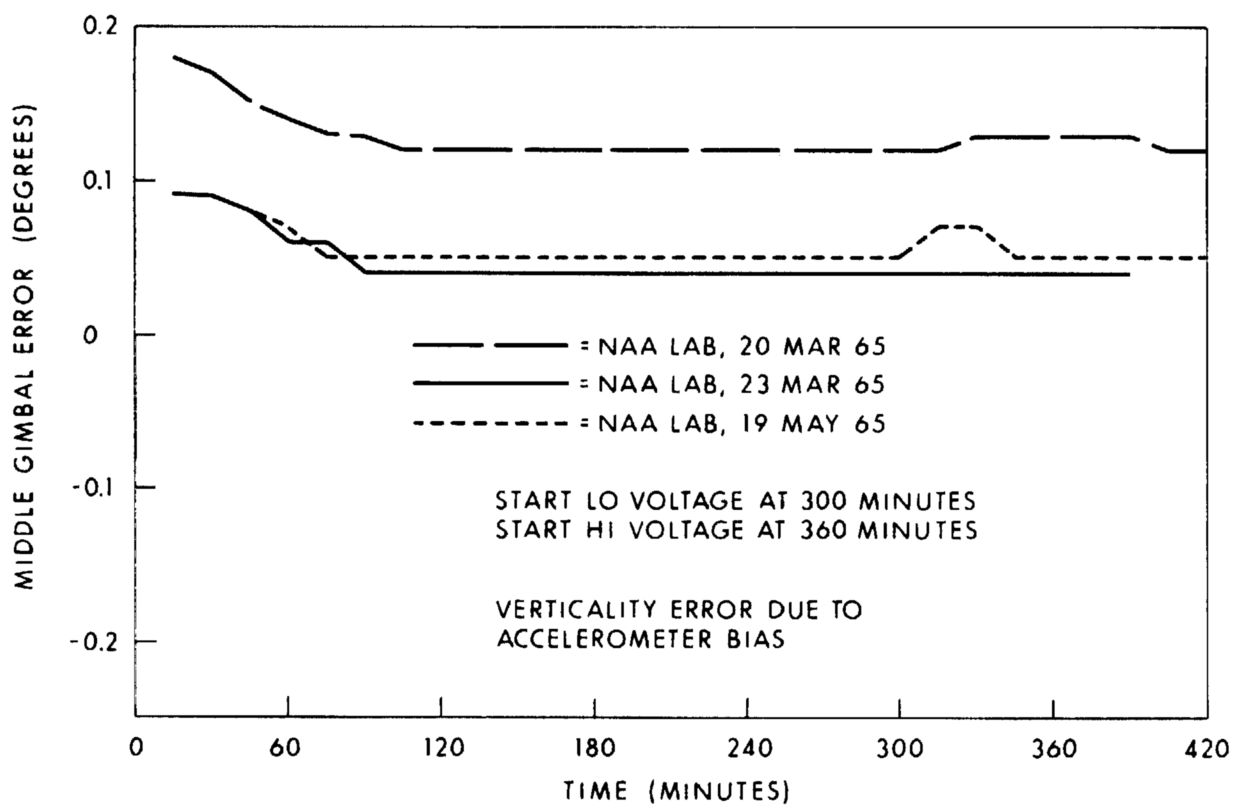
GYROCOMPASSING TEST RESULTS - INNER GIMBAL ERROR - G&N 17

(DESIRED CDU MINUS OBSERVED CDU)



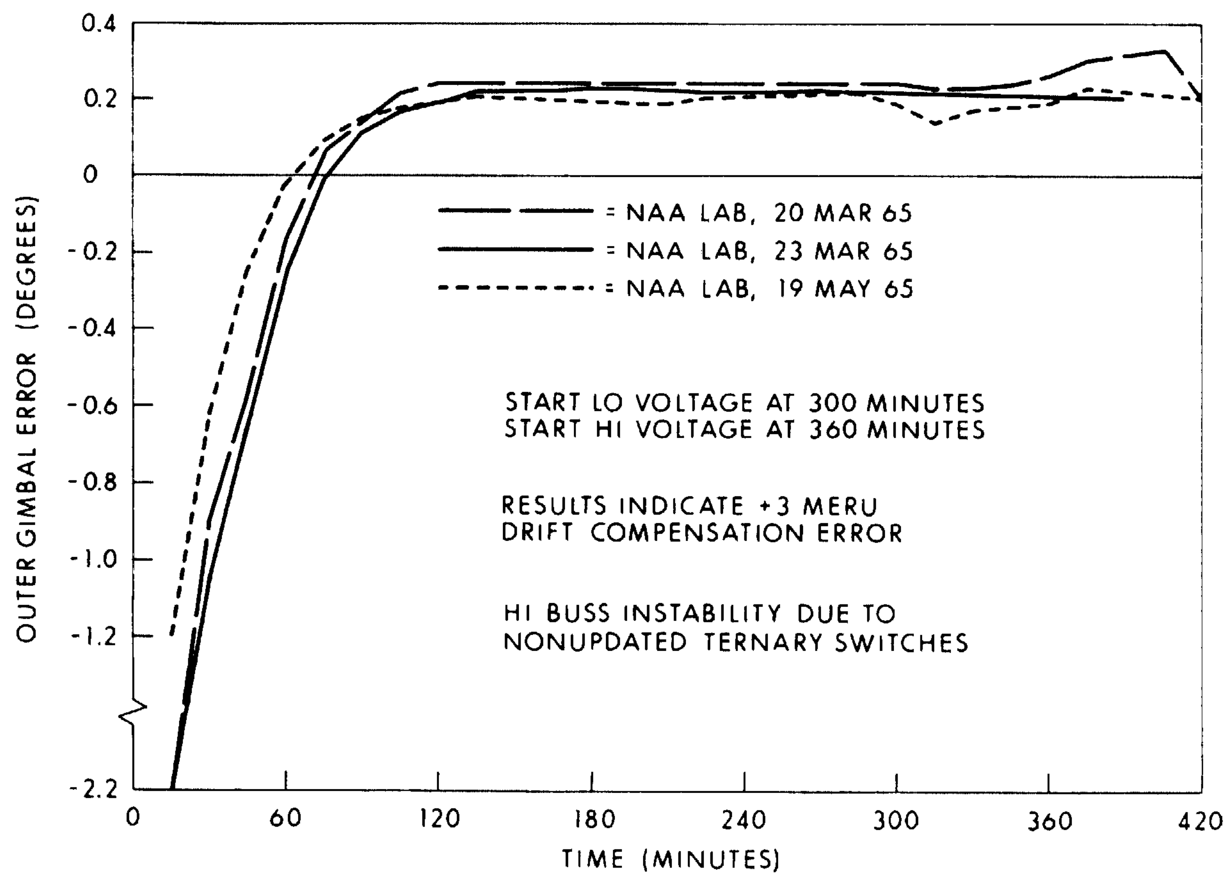
GYROCOMPASSING TEST RESULTS - MIDDLE GIMBAL ERROR - G&N 17

(DESIRED CDU MINUS OBSERVED CDU)



GYROCOMPASSING TEST RESULTS - OUTER GIMBAL ERROR - G&N 17

(DESIRED CDU MINUS OBSERVED CDU)



STANDARD DEVIATION (1σ) OF THE
IRIG AND PIPA PARAMETER UNCERTAINTIES

Parameter	IMU Axis		
	X	Y	Z
Accelerometer Bias (cm/sec^2)	.136	.215	.066
Scale Factor (Δ SF/SF ppm)	75	96	150
Bias Drift (meru)	2.6	1.4	1.6
ADSRA (meru/g)	4.6	2.0	1.8
ADIA (meru/g)	2.5	3.4	2.9

Data is based upon performance in the IMU. The first data was taken 26 February 1965 and the last data was taken 3 September 1965. If multiple points were taken in a single eight hour period, only the average of the set of points was used and/or a single point. Point-to-point stability in operation is much better than the above data. The error computation for Mission 202 uses the above data.

[redacted]

TABLE 7-A-1 202 TRAJECTORY INDICATION UNCERTAINTIES

Due to C.M. IMU Component Error Uncertainties where these are equal to Block II Specifications (1σ)

Event	Time from Start mins.	Update Time (Perfect update assumed)	RSS Position Uncert. (n. mi) Alt.	RSS Position Uncert. (n. mi) Track	RSS Position Uncert. (n. mi) Range	RSS Velocity Uncert. (ft/sec) Alt.	RSS Velocity Uncert. (ft/sec) Track	RSS Velocity Uncert. (ft/sec) Range	Rss Flight Path Angle Uncert. deg.
SIVB Cutoff	10.2	1) No update	0.34	2.10	0.15	8.4	48.5	3.3	
SPS 1st Burn Cutoff	14.4	1) No update	0.71	4.22	0.43	12.2	52.7	5.4	
		2) Update prior to SPS 1st Burn	0.05	0.19	0.03	2.5	10.9	1.5	
Coast End (SPS 2nd Burn Ignit.)	67.1	1) No update	3.22	3.85	12.09	73.7	47.6	11.3	
		2) Update prior to SPS 1st Burn	1.10	0.10	2.96	18.7	10.5	4.2	
		3) Update prior to SPS 2nd Burn	0	0	0	0	0	0	
SPS 2nd Burn Cutoff	68.6	1) No update	3.10	4.56	12.46	76.7	46.4	11.8	
		2) Update prior to SPS 1st Burn	1.08	0.27	3.11	19.9	12.2	4.9	
		3) Update prior to SPS 2nd Burn	0.01	0.02	0.01	1.7	2.3	0.9	
Entry Start (400,000 ft. altitude)	73.4	1) No update	2.35	6.52	13.56	85.3	32.3	12.1	0.095
		2) Update prior to SPS 1st Burn	0.68	0.85	3.62	22.8	10.8	5.0	0.031
		3) Update prior to SPS 2nd Burn	0.11	0.12	0.04	2.1	2.1	0.6	0.011
									C.E.P. n. mi.
Entry End (24,000 ft. altitude)	87.3	1) No update	3.90	8.45	13.68	101.2	23.7	34.6	13.1
		2) Update prior to SPS 1st Burn	1.43	3.07	4.16	33.0	45.0	11.2	4.3
		3) Update prior to SPS 2nd Burn	0.99	1.75	0.53	24.5	44.9	7.8	1.3

NOTE: Asterisks (*) on detailed tables denote particular IMU uncertainties with most significant effects on position and velocity uncertainties.

Block II Specifications (1σ) for IMU Error Uncertainties

	X	Y	Z	
Accelerometer bias (ACB)	0.20	0.20	0.20	cm/sec^2
Accelerometer scale factor (SFE)	100	100	100	PPM
Accelerometer non-linearity	10	10	10	$\mu g/g^2$
Gyro bias drift (BD)	2	2	2	meru
Gyro input axis accel. sens. drift (ADIA)	8	8	8	meru/g
Gyro spin ref. axis accel sens. drift (ADSRA)	5	5	5	meru/g
Gyro accel. squared sens. drift	0.3	0.3	0.3	$meru/g^2$
Accelerometer IA misalignment				
Non-orthogonality X to Y	0.14	---	---	mr.
Non-orthogonality X to Z	0.14	---	---	mr.
Y about X_{SM}	---	0.10	---	mr.
Gyro IA misalignment				
Z about X_{SM}	---	---	0.50	mr.

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Table 7-A-2 Uncertainties at SIVB Cutoff with No Update

Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50 mr		-2,677			-10.19	
		About Y_I		0.06 mr	250		-404	1.17		-1.08
		About Z_I		0.06 mr		321			.75	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.14 mr	0		0	0		0
		X to Z		0.14 mr	802	·	-223	3.33		-.86
	Accel. IA Mlm	Y about X_I		0.10 mr		535			2.03	
	Bias Error	* ACBX	Eff on Init Mlm		0		0	0		0
			Eff on Pwr Flt	.20 cm/sec²	-1275		352	-4.54		1.16
			Combined Eff		-1275		352	-4.54		1.16
		ACBY	Eff on Init Mlm			+1091			2.54	
			Eff on Pwr Flt	.20 cm/sec²		-1161			-3.64	
			Combined Eff			-70			-1.10	
		* ACBZ	Eff on Init Mlm		-851		1370	-4.00		3.69
			Eff on Pwr Flt	.20 cm/sec²	-344		-1111	-1.21		-3.47
			Combined Eff		-1195		259	-5.20		.22
	Scale Factor Error	* SFEX		100 PPM	-609		168	-1.76		.41
		SFEY		100 PPM		0			0	
		* SFEZ		100 PPM	-158		-514	-.65		-1.96
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g²	-83		23	-0.21		0.05
		NCYY		10 μg/g²		0			0	
		NCZZ		10 μg/g²	-23		-73	-0.09		-0.28
GYRO	Bias Drift	BDX	Eff on Init Mlm			781			2.97	
			Eff on Pwr Flt	2 meru		-184			-1.09	
			Combined Eff			597			1.88	
		BDY	Eff on Init Mlm		3	-3156	0	.02	-12.01	0
			Eff on Pwr Flt	2 meru	159	0	-156	1.03	0	-.72
			Combined Eff		162	-3156	-156	1.04	-12.01	-.72
		* BDZ	Eff on Init Mlm		-8	11708	2	-.06	44.57	0
			Eff on Pwr Flt	2 meru	0	106	0	0	.41	0
			Combined Eff		-8	11813	2	-.06	44.98	0
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm			3123			11.90	
			Eff on Pwr Flt	8 meru/g		-806			-3.90	
			Combined Eff			2317			8.00	
		ADSRAY	Eff on Init Mlm		0		0	0		0
			Eff on Pwr Flt	5 meru/g	-359		314	-2.47		1.69
			Combined Eff		-359		314	-2.47		1.69
		ADIAZ	Eff on Init Mlm			0			0	
			Eff on Pwr Flt	8 meru/g		327			1.50	
			Combined Eff			327			1.50	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g²		-43			-0.19	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g²	31		-28	0.21		-0.14
		$A^2D_{(IA)(IA)Z}$		.3 meru/g²		18			0.08	
Root Sum Square Error (in ft and ft/sec)					2078	12,763	909	8.43	48.45	3.27
" " " " (in n. mi. and ft/sec)					0.34	2.10	0.15	8.4	48.5	3.3

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Table 7-A-3 Uncertainties at SPS 1st Burn Cutoff with No Update

	Error			RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.50mr		-5,394			-11.12	
		About Y_I		0.06mr	405		-808	1.32		-1.35
		About Z_I		0.06mr		500			.62	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.14mr	0		0	0		0
		X to Z *		0.14mr	1635		-913	4.37		-2.0
	Accel. IA Mlm	Y about X_I		0.10mr		1079			2.23	
	Bias Error	* ACBX	Eff on Init Mlm	.20cm/sec²	0		0	0		0
			Eff on Pwr Flt		-2487		1382	-6.68		3.04
			Combined Eff		-2487		1382	-6.68		3.04
		ACBY	Eff on Init Mlm	.20 cm/sec²		1698			2.11	
			Eff on Pwr Flt			-2218			-4.63	
			Combined Eff			-519			-2.51	
		* ACBZ	Eff on Init Mlm	.20 cm/sec²	-1372		2743	-4.48		4.59
			Eff on Pwr Flt		-1310		-1841	-3.37		-3.78
			Combined Eff		-2682		902	-7.85		.81
	Scale Factor Error *	SFEX		100 PPM	-1026		556	-2.20		.85
		SFEY		100 PPM		0			0	
		SFEZ		100 PPM	-637		-902	-1.62		-1.82
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-132		71	0.27		0.10
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-90		-126	-0.22		-0.23
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		1573			3.24	
			Eff on Pwr Flt			-506			-1.49	
			Combined Eff			1067			1.75	
		BDY	Eff on Init Mlm	2 meru	12	-6359	-3	.06	-13.10	-.01
			Eff on Pwr Flt		381	-1	-469	1.42	0	-1.19
			Combined Eff		393	-6360	-472	1.48	-13.10	-1.20
		* BDZ	Eff on Init Mlm	2 meru	-44	23590	14	-.24	48.61	.04
			Eff on Pwr Flt		0	213	0	0	.38	0
			Combined Eff		-44	23802	14	-.24	48.99	.04
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		6294			12.96	
			Eff on Pwr Flt			-1891			-4.67	
			Combined Eff			4403			8.29	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		-912		1051	-3.42		2.84
			Combined Eff		-912		1052	-3.42		2.84
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			717			1.44	
			Combined Eff			717			1.44	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g²		-95			-0.22	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g²	78		-92	0.29		-0.24
		$A^2D_{(IA)(IA)Z}$		.3 meru/g²		40			0.08	
Root Sum Square Error (in ft and ft/sec)					4,324	25,667	2,587	12.20	52.73	5.43
" " " " (in n. mi. and ft/sec)					0.71	4.22	0.43	12.2	52.7	5.4

[redacted]

Table 7-A-4 Uncertainties at SPS 1st Burn C. O. with Update before 1st Burn

	Error			RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		-251			-2.29	
		About Y_I		.06 mr	24		-20	.22		-1.6
		About Z_I		.06 mr		3			.02	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	60		-37	.56		-.34
	Accel. IA Mlm	Y about X_I		.10 mr		50			.47	
	Bias Error	* ACBX	Eff on Init Mlm	$.20 cm/sec^2$	0		0	0		0
			Eff on Pwr Flt		-158		96	-1.35		.82
			Combined Eff		-158		96	-1.35		.82
		ACBY	Eff on Init Mlm	$.20 cm/sec^2$		11			.06	
			Eff on Pwr Flt			-183			-1.53	
			Combined Eff			-171			-1.47	
		* ACBZ	Eff on Init Mlm	$.20 cm/sec^2$	-81		65	-.79		.54
			Eff on Pwr Flt		-99		-155	-.85		-1.30
			Combined Eff		-180		-90	-1.64		-.76
	Scale Factor Error	SFEX		100 PPM	-6		3	-.03		.03
		SFEY		100 PPM		0			0	
		SFEZ		100 PPM	-27		-42	-.25		-.39
	Accel. Sq. Sensitive Indication Error	NCXX		$10 \mu g/g^2$	0		0	0		0
		NCYY		$10 \mu g/g^2$		0			0	
		NCZZ		$10 \mu g/g^2$	-2		-2	-0.02		-0.02
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		73			0.67	
			Eff on Pwr Flt			-52			-0.51	
			Combined Eff			21			0.16	
		BDY	Eff on Init Mlm	2 meru	0	-296	0	0	-2.70	0
			Eff on Pwr Flt		43	0	-32	.43	0	-.30
			Combined Eff		43	-296	-32	.43	-2.70	-.30
		* BDZ	Eff on Init Mlm	2 meru		1097			10.02	
			Eff on Pwr Flt			6			.03	
			Combined Eff			1103			10.05	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		291			2.69	
			Eff on Pwr Flt			131			-1.22	
			Combined Eff			160			1.47	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		-106		83	-1.06		.72
			Combined Eff		-106		83	-1.06		.72
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			23			.11	
			Combined Eff			23			.11	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		$.3 meru/g^2$		-5			-0.05	
		$A^2D_{(SRA)(SRA)Y}$		$.3 meru/g^2$	9		-7	0.09		-0.06
		$A^2D_{(IA)(IA)Z}$		$.3 meru/g^2$		1			0.01	
Root Sum Square Error (in ft and ft/sec)					318	1,184	170	2.50	10.87	1.47
" " " " (in n. mi. and ft/sec)					0.05	0.19	0.03	2.5	10.9	1.5

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Table 7-A-5 Uncertainties at SPS 2nd Burn Ignition with No Update

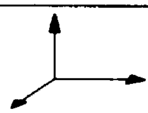
Error 				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		4,913			10.03	
		About Y_I		.06 mr	-3,861		4,980	-6.09		2.88
		About Z_I		.06 mr		-478			-.52	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	155		-16203	14.72		1.81
	Accel. IA Mlm	Y about X_I		.10 mr		-982			-2.00	
	Bias Error	* ACBX	Eff on Init Mlm	$.20 cm/sec^2$	0		0	0		0
			Eff on Pwr Flt		-226		24824	-22.53		-2.76
			Combined Eff		-226		24824	-22.53		-2.76
		ACBY	Eff on Init Mlm	$.20 cm/sec^2$	-37	-1622	260	-.25	-1.78	.01
			Eff on Pwr Flt		24	2017	-327	.28	4.18	.02
			Combined Eff		-12	395	-67	.03	2.39	.03
		* ACBZ	Eff on Init Mlm	$.20 cm/sec^2$	13108	182	-16911	20.75	.25	-9.81
			Eff on Pwr Flt		-25261	-428	72369	-76.18	-.70	14.13
			Combined Eff		-12154	-247	55458	-55.42	.45	4.32
	Scale Factor Error	SFEX		100 PPM	-1638		11551	-11.35		0
		SFEY		100 PPM		0			0	
	*	SFEZ		100 PPM	-12223		35017	-36.86		6.84
	Accel. Sq. Sensitive Indication Error	NCXX		$10\ \mu g/g^2$	-256		1529	-1.53		0.03
		NCYY		$10\ \mu g/g^2$		0			0	
		NCZZ		$10\ \mu g/g^2$	-1602	-27	4630	-4.87		0.89
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-1433			-2.93	
			Eff on Pwr Flt			437			1.38	
			Combined Eff			-996			-1.55	
		BDY	Eff on Init Mlm	2 meru	71	5792	-923	.80	11.82	.03
			Eff on Pwr Flt		-3129	-37	2204	-3.46	-.05	2.51
			Combined Eff		-3057	5754	1281	-2.66	11.77	2.55
		* BDZ	Eff on Init Mlm	2 meru	-265	-21484	3424	-2.95	-43.86	-.14
			Eff on Pwr Flt		3	-196	31	-.03	-.35	
			Combined Eff		-268	-21680	3455	-2.98	-44.22	-.14
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		5731			-11.71	
			Eff on Pwr Flt			1680			4.26	
			Combined Eff			-4051			-7.46	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		7398		-4773	7.84		-5.98
			Combined Eff		7398		-4773	7.84		-5.98
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			656			-1.29	
			Combined Eff			656			-1.29	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		$.3\ meru/g^2$		86			0.20	
		$A^2D_{(SRA)(SRA)Y}$		$.3\ meru/g^2$	-621		406	-0.65		-.50
		$A^2D_{(IA)(IA)Z}$		$.3\ meru/g^2$		-36			-0.07	
Root Sum Square Error (in ft and ft/sec)					19,544	23,378	73,480	73.65	47.57	11.31
" " " " (in n. mi. and ft/sec)					3.22	3.85	12.09	73.7	47.6	11.3

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Table 7-A-6 Uncertainties at SPS 2nd Burn Ignition with Update before 1st Burn

	Error			RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		133			2.22	
		About Y_I		.06 mr	-514		284	-.54		.40
		About Z_I		.06 mr		-3			-.02	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	-1005		164	-.73		.84
	Accel. IA Mlm	Y about X_I		.10 mr		-26			-.44	
	Bias Error	*ACBX	Eff on Init Mlm	$.20 cm/sec^2$	0		0	0		0
			Eff on Pwr Flt		2369		-251	1.61		-1.97
			Combined Eff		2369		-251	1.61		-1.97
		ACBY	Eff on Init Mlm	$.20 cm/sec^2$		-9			-.05	
			Eff on Pwr Flt			104			1.49	
			Combined Eff			96			1.44	
		*ACBZ	Eff on Init Mlm	$.20 cm/sec^2$	1748		-961	1.85		-1.39
			Eff on Pwr Flt		-6959		18036	-19.37		4.12
			Combined Eff		-5211		17075	-17.51		2.74
	Scale Factor Error	SFEX		100 PPM	35		18	0		-.03
		SFEY		100 PPM		0			0	
		SFEZ		100 PPM	-2076		5368	-5.77		1.23
	Accel. Sq. Sensitive Indication Error	NCXX		$10\ \mu g/g^2$	0		0	0		0
		NCYY		$10\ \mu g/g^2$		0			0	
		NCZZ		$10\ \mu g/g^2$	-128		330	-0.35		0.08
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-39			-0.65	
			Eff on Pwr Flt			26			0.49	
			Combined Eff			-13			-0.16	
		BDY	Eff on Init Mlm	2 meru	-20	157	-46	.01	2.62	.03
			Eff on Pwr Flt		-947	-10	510	-.99	-.02	.75
			Combined Eff		-967	148	464	-.98	2.60	.77
		*BDZ	Eff on Init Mlm	2 meru		-580			-9.72	
			Eff on Pwr Flt			-5			-.03	
			Combined Eff			-584			-9.75	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		-154			-2.59	
			Eff on Pwr Flt			70			1.18	
			Combined Eff			-83			-1.41	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		2344		-1273	2.47		-1.86
			Combined Eff		2344		-1273	2.47		-1.86
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			-17			-.11	
			Combined Eff			-17			-.11	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		$.3\ meru/g^2$		3			0.05	
		$A^2D_{(SRA)(SRA)Y}$		$.3\ meru/g^2$	-194		106	-0.20		0.15
		$A^2D_{(IA)(IA)Z}$		$.3\ meru/g^2$		-1			-0.01	
Root Sum Square Error (in ft and ft/sec)					6,696	631	17,958	18.72	10.54	4.23
" " " " (in n. mi. and ft/sec)					1.10	0.10	2.96	18.7	10.5	4.2

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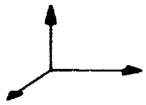
Table 7-A- 7 Uncertainties at SPS 2nd Burn Cutoff with No Update



Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		5, 833			10. 05	
		About Y_I		.06 mr	-3, 870		5667	6. 54		3. 02
		About Z_I		.06 mr		-516			-.33	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	-210		-16026	15. 07		
	Accel. IA Mlm	Y about X_I		.10 mr		-1167.			2. 00	
	Bias Error	* ACBX	Eff on Init Mlm	20 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		367		24528	-22. 33		-3. 55
			Combined Eff		367		24528	-22, 33		-3, 55
		ACBY	Eff on Init Mlm	.20 cm/sec^2		-1757			-1. 13	
			Eff on Pwr Flt			2360			3. 32	
			Combined Eff			604			2. 19	
		* ACBZ	Eff on Init Mlm	.20 cm/sec^2	13140	205	-19242	22. 25	.27	-10. 28
			Eff on Pwr Flt		-24444	-495	76347	-80. 1	-.74	14. 42
			Combined Eff		-11304	-290	57105	-57. 85	-.47	4. 14
	Scale Factor Error	SFEX		100 PPM	-1441		11707	-11. 52		-.24
		SFEY		100 PPM		0			0	
		* SFEZ		100 PPM	-11839		36926	-39. 00		6. 63
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-232	-7	1558	-1. 57	-0. 01	0. 01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-1550	-32	4883	-5. 14	0	0. 88
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-1701			-2. 93	
			Eff on Pwr Flt			595			2. 1	
			Combined Eff			-1106			-0. 83	
		BDY	Eff on Init Mlm	2 meru	47	6876	-925	.84	11. 86	.05
			Eff on Pwr Flt		-3138	-43	2807	-2. 51	-.05	3. 28
			Combined Eff		-3091	6834	1882	-1. 68	11. 81	3. 33
		* BDZ	Eff on Init Mlm	2 meru	-174	-25508	3432	-3, 10	-44, 00	-.21
			Eff on Pwr Flt		-2	-168	31	-.03	1. 01	0
			Combined Eff		-176	-25676	3462	-3, 14	-42, 99	-.21
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		-6806			-11. 74	
			Eff on Pwr Flt			2077			4. 42	
			Combined Eff			-4730			-7. 33	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		7550		-6152	8. 23		-6. 56
			Combined Eff		7550		-6152	8. 23		-6. 56
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			-723			-.16	
			Combined Eff			-723			-.16	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 $meru/g^2$		104			0. 20	
		$A^2D_{(SRA)(SRA)Y}$		.3 $meru/g^2$	-634		521	-0. 70		0. 54
		$A^2D_{(IA)(IA)Z}$		.3 $meru/g^2$		-40			-0. 01	
Root Sum Square Error (in ft and ft/sec)					18, 831	27, 680	75, 710	76. 67	46. 39	11. 75
" " " " (in n. mi and ft/sec)					3. 10	4. 56	12. 46	76. 7	46. 4	11. 8

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Table 7-A-8 Uncertainties at SPS 2nd Burn C. O. with Update before 1st Burn

	Error			RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		364			2.85	
		About Y_I		.06 mr	-527		381	-.48		.50
		About Z_I		.06 mr		1.5			12	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	-1044		349	-.73		.79
	Accel. IA Mlm	Y about X_I		.10 mr		-74			-.56	
	Bias Error	ACBX	Eff on Init Mlm	.20 cm/sec²	0		0	0		0
			Eff on Pwr Flt		2504		-716	2.45		-2.45
			Combined Eff		2504		-716	2.45		-2.45
		ACBY	Eff on Init Mlm	.20 cm/sec²		6			.40	
			Eff on Pwr Flt			212			.86	
			Combined Eff			218			1.26	
		*ACBZ	Eff on Init Mlm	20 cm/sec²	1787		-1294	1.62		-1.69
			Eff on Pwr Flt		-6775		19175	-20.18		4.61
			Combined Eff		-4988		17881	-18.56		2.92
	Scale Factor Error	SFEX		100 PPM	44		6	-.21		-.18
		SFEY		100 PPM		0			0	
		*SFEZ		100 PPM	-2030		5697	-61 8		1.12
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g²	1		0	0.01		-0.01
		NCYY		10 μg/g²		0			0	
		NCZZ		10 μg/g²	-125		351	-0.04		0.08
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-106			-0.83	
			Eff on Pwr Flt			105			1.26	
			Combined Eff			-1			0.43	
		BDY	Eff on Init Mlm	2 meru	-24	420	-41	.01	3.36	.03
			Eff on Pwr Flt		-919	-11	712	.27	.02	1.45
			Combined Eff		-943	418	671	.28	3.34	1.49
		*BDZ	Eff on Init Mlm	2 meru		-1593			-12.45	
			Eff on Pwr Flt			52			1.30	
			Combined Eff			-1541			-11.15	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		-426			-3.33	
			Eff on Pwr Flt			192			1.54	
			Combined Eff			-234			-1.79	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		2396		-1718	2.11		-2.28
			Combined Eff		2396		-1718	2.11		-2.28
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			197			.95	
			Combined Eff			197			.95	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g²		8			0.06	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g²	-198		143	-0.18		0.19
		$A^2D_{(IA)(IA)Z}$		.3 meru/g²		1			0.05	
Root Sum Square Error (in ft and ft/sec)					6.582	1.670	18,882	19.85	12.24	4.91
" " " " (in n. mi. and ft/sec)					1.08	0.27	3.11	19.9	12.2	4.9

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Table 7-A-9 Uncertainties at SPS 2nd Burn C.O. with Update before 2nd Burn

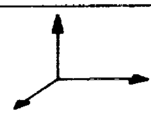
Error 				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		29			0.65	
		About Y_I		.06 mr	6		3	.14		.06
		About Z_I		.06 mr		6			.14	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	7		-5	.15		-.11
	Accel. IA Mlm	Y about X_I		.10 mr		6			.15	
	Bias Error	ACBX	Eff on Init Mlm	.20 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		23		-14	.51		-.34
			Combined Eff		23		-14	.51		-.34
		ACBY	Eff on Init Mlm	.20 cm/sec^2		20			.46	
			Eff on Pwr Flt			-27			-.60	
			Combined Eff			7			-.14	
		ACBZ	Eff on Init Mlm	.20 cm/sec^2	-22		-9	-.49		-.22
			Eff on Pwr Flt		14		22	.34		.49
			Combined Eff		-7		13	-.14		.27
	Scale Factor Error	SFEX		100 PPM	9		-6	.18		-.12
		SFEY		100 PPM		0			0	
		SFEZ		100 PPM	-4		-5	-.07		-.10
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g^2	1		0	0.01		-0.01
		NCYY		10 μg/g^2		0			0	
		NCZZ		10 μg/g^2	0		0	0		0
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-8			-0.19	
			Eff on Pwr Flt			34			0.78	
			Combined Eff			26			0.59	
		* BDY	Eff on Init Mlm	2 meru	0	-40	0	0	-.91	0
			Eff on Pwr Flt		61	0	29	1.41	0	.65
			Combined Eff		61	-40	29	1.41	-.91	.65
		* BDZ	Eff on Init Mlm	2 meru		-124			-2.80	
			Eff on Pwr Flt			58			1.33	
			Combined Eff			-66			-1.47	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		-32			-.77	
			Eff on Pwr Flt			16			.38	
			Combined Eff			-16			-.38	
		* ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		-31		-14	-.70		-.30
			Combined Eff		-31		-14	-.70		-.30
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			46			1.06	
			Combined Eff			46			1.06	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		3 meru/g^2		1			0.02	
		$A^2D_{(SRA)(SRA)Y}$		3 meru/g^2	2		1	0.06		0.03
		$A^2D_{(IA)(IA)Z}$		meru/g^2		2			0.05	
Root Sum Square Error (in ft and ft/sec)					74	100	39	1.69	2.26	.86
" " " " (in n. mi. and ft/sec)					0.01	0.02	0.01	1.7	2.3	0.9

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Table 7-A-10 Uncertainties at Entry Start with No Update

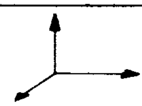
Error 				RMS Error	Final Position Error in Local Axes (in feet) Att.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Att.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		8,440			7.06	
		About Y_I		.06 mr	-3,444		8039	-8.42		3.11
		About Z_I		.06 mr		-584			-.11	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	-1705		-14972	15.15		2.51
	Accel. IA Mlm	Y about X_I		.10 mr		-1688			-1.41	
	Bias Error	*ACBX	Eff on Init Mlm	.20 cm/sec^2	0	0	0	0	0	0
			Eff on Pwr Flt		2809	-104	22676	-22.59	-.08	-4.54
			Combined Eff		2809	-104	22676	-22.59	-.08	-4.54
		ACBY	Eff on Init Mlm	.20 cm/sec^2	-10	-1984	273	-.30	-.35	0
			Eff on Pwr Flt		-16	3195	-319	.34	2.16	.03
			Combined Eff		-26	1211	-46	.04	1.81	.03
		*ACBZ	Eff on Init Mlm	.20 cm/sec^2	11693	292	-27293	28.57	.31	-10.53
			Eff on Pwr Flt		-18124	-716	89024	-92.39	-.72	13.79
			Combined Eff		-6431	-425	61731	-63.83	-.41	3.26
	Scale Factor Error	SFEX		100 PPM	-432		11972	-12.47		-.44
		SFEY		100 PPM		0			0	
		*SFEZ		100 PPM	-8896		43001	-45.11		6.47
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-103		1625	-1.7	0	0
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-1154		5678	-5.93		0.85
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-2462			-2.06	
			Eff on Pwr Flt			1177			1.73	
			Combined Eff			-1285			-0.33	
		BDY	Eff on Init Mlm	2 meru	-41	9949	-903	.96	8.33	.09
			Eff on Pwr Flt		-2565	-61	4872	-3.70	-.07	2.89
			Combined Eff		-2606	9888	3969	2.74	8.26	2.98
		*BDZ	Eff on Init Mlm	2 meru	153	-36910	3351	-3.55	-30.89	-.31
			Eff on Pwr Flt		0	138	31	-.03	1.01	0
			Combined Eff		153	-36772	3381	-3.58	-29.88	-.31
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		-9846			-8.26	
			Eff on Pwr Flt			3251			3.30	
			Combined Eff			-6595			-4.96	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		7181		-11098	11.76		-6.89
			Combined Eff		7181		-11098	11.76		-6.89
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			-727			.15	
			Combined Eff			-727			.15	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 $meru/g^2$		156	936		0.15	
		$A^2D_{(SRA)(SRA)Y}$		.3 $meru/g^2$	-603			-0.99		0.58
		$A^2D_{(IA)(IA)Z}$		.3 $meru/g^2$		-41			0.01	
Root Sum Square Error (in ft and ft/sec)					14,263	39,645	82,415	85.28	32.27	12.12
" " " " (in n. mi. and ft/sec)					2.35	6.52	13.56	85.3	32.3	12.1

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Table 7-A-11 Uncertainties at Entry Start with Update before 1st Burn

		Error		RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		1,179			2.52	
		About Y_I		.06 mr	-488		732	-.71		.50
		About Z_I		.06 mr		38			.11	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	-1080		1020	-1.29		.89
	Accel. IA Mlm	Y about X_I		.10 mr		-235			-.50	
	Bias Error	*ACBX	Eff on Init Mlm	.20 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		2772		-2577	3.61		-2.96
			Combined Eff		2772		-2577	3.61		-2.96
		ACBY	Eff on Init Mlm	.20 cm/sec^2		125			.37	
			Eff on Pwr Flt			453			.72	
			Combined Eff			579			1.10	
		*ACBZ	Eff on Init Mlm	.20 cm/sec^2	1654		-2486	2.41		-1.69
			Eff on Pwr Flt		-5119		22889	-23.4		4.37
			Combined Eff		-3465		20403	-20.99		2.68
	Scale Factor Error	SFEX		100 PPM	88		-79	.18		-.21
		SFEY		100 PPM		0			0	
		SFEZ		100 PPM	-1623		6762	-7.27		1.16
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	4		-5	0.01		-0.01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-96		418	-0.43		0.08
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-344			-0.74	
			Eff on Pwr Flt			471			1.14	
			Combined Eff			127			0.4	
		BDY	Eff on Init Mlm	2 meru	-35	1390	-18	.01	2.98	.04
			Eff on Pwr Flt		-444	-17	1349	.17	-.02	.93
			Combined Eff		-479	1373	1331	.17	2.96	.97
		*BDZ	Eff on Init Mlm	2 meru		-5158			-11.02	
			Eff on Pwr Flt			431			1.19	
			Combined Eff			-4726			-9.82	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		-1376			-2.94	
			Eff on Pwr Flt			630			1.34	
			Combined Eff			-746			-1.6	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		2205		-3317	3.17		-2.28
			Combined Eff		2205		-3317	3.17		-2.28
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			295			0.87	
			Combined Eff			295			0.87	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g^2		26			0.06	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g^2	-182		275	-0.26		0.19
		$A^2D_{(IA)(IA)Z}$		.3 meru/g^2		15			0.04	
Root Sum Square Error (in ft and ft/sec)					4,121	5,164	21,983	22.78	10.79	4.96
" " " " (in n.mi. and ft/sec)					0.68	0.85	3.62	22.8	10.8	5.0

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Table 7-A-12 Uncertainties at Entry Start with Update before 2nd Burn

	Error			RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		219			0.60	
		About Y_I		.06 mr	57		2	0.18		0
		About Z_I		.06 mr		45			0.12	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	37		-52	0.12		-0.14
	Accel. IA Mlm	Y about X_I		.10 mr		44			0.12	
	Bias Error	*ACBX	Eff on Init Mlm	.20 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		121		-172	0.39		-0.48
			Combined Eff		121		-172	0.39		-0.48
		ACBY	Eff on Init Mlm	.20 cm/sec^2		152			0.43	
			Eff on Pwr Flt			-203			-0.56	
			Combined Eff			-50			-0.13	
		ACBZ	Eff on Init Mlm	.20 cm/sec^2	-191		-5	-0.61		0
			Eff on Pwr Flt		182		108	0.57		0.29
			Combined Eff		-9		103	-0.04		0.29
	Scale Factor Error	SFEX		100 PPM	44		-65	0.15		-0.18
		SFEY		100 PPM		0			0	
		SFEZ		100 PPM	-40		-24	-0.13		0.06
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	3		-5	0.01		-0.01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	2		1	0.01		0
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-64			-0.18	
			Eff on Pwr Flt			260			0.72	
			Combined Eff			196			0.54	
		*BDY	Eff on Init Mlm	2 meru	0	-307	0	0	-0.84	0
			Eff on Pwr Flt		559	0	17	1.79	0	0.02
			Combined Eff		559	-307	17	1.79	-0.84	0.02
		*BDZ	Eff on Init Mlm	2 meru		-941			-2.57	
			Eff on Pwr Flt			445			1.22	
			Combined Eff			-496			-1.35	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		-256			-0.70	
			Eff on Pwr Flt			125			0.35	
			Combined Eff			-131			-0.35	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		-275		-81	-0.89		0
			Combined Eff		-275		-81	-0.89		0
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			353			0.97	
			Combined Eff			353			0.97	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g^2		5			0.01	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g^2	22		1	0.07		0
		$A^2D_{(IA)(IA)Z}$		.3 meru/g^2		18			0.05	
Root Sum Square Error (in ft and ft/sec)					642	758	234	2.06	2.07	0.61
" " " " (in n.mi. and ft/sec)					0.11	0.12	0.04	2.1	2.1	0.6

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Table 7-A-13 Uncertainties at Entry End (24,000 ft) with No Update

Error					RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)			.50 mr		10024			0.22	
		About Y_I			.06 mr	-5235		11618	-15.99		-2.55
		About Z_I			.06 mr		-818			-.87	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y			.14 mr	0		0	0		0
		X to Z			.14 mr	-506		-10168	11.84		5.93
	Accel. IA Mlm	Y about X_I			.10 mr		2005			.06	
	Bias Error	ACBX	Eff on Init Mlm		.20 cm/sec^2	0		0	0		0
			Eff on Pwr Flt			474		11948	-18.84		-15.93
			Combined Eff			474		11948	-18.84		-15.93
		ACBY	Eff on Init Mlm		.20 cm/sec^2		-2781			-2.97	
			Eff on Pwr Flt				1067			-6.80	
			Combined Eff				-1714			-9.77	
		*ACBZ	Eff on Init Mlm		.20 cm/sec^2	17773		-39451	54.31		8.69
			Eff on Pwr Flt			-27310		99038	-113.85		-33.23
			Combined Eff			-9536		59587	-59.54		-24.53
	Scale Factor Error *	SFEX			100 PPM	-1914		11160	-12.85		-2.73
		SFEY			100 PPM		0			-.05	
		SFEZ			100 PPM	-15415		48444	-61.18		-15.10
	Accel. Sq. Sensitive Indication Error	NCXX			10 $\mu g/g^2$	-366		1353	-2.04		-1.22
		NCYY			10 $\mu g/g^2$		-11			-0.05	
		NCZZ			10 $\mu g/g^2$	-1935		6350	-7.68		-2.07
GYRO	Bias Drift	BDX	Eff on Init Mlm		2 meru		-2924			-0.06	
			Eff on Pwr Flt				2843			7.72	
			Combined Eff				-81			7.66	
		*BDY	Eff on Init Mlm		2 meru	-98	-14089	842	-.59	-.30	-.56
			Eff on Pwr Flt			-7925	-71	7247	-29.85	.05	-6.05
			Combined Eff			-8023	-14160	8175	-30.44	-.25	-6.60
		*BDZ	Eff on Init Mlm		2 meru	-298	-43100	2574	-1.81	-.93	-1.71
			Eff on Pwr Flt			2	-4403	15	-.11	-16.85	-.54
			Combined Eff			-297	-47503	2589	-1.91	-17.78	-2.25
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm		8 meru/g		-11696			-.26	
			Eff on Pwr Flt				3926			-2.43	
			Combined Eff				-7770			-2.69	
		*ADSRAY	Eff on Init Mlm		5 meru/g	0	0	0	0	0	0
			Eff on Pwr Flt			11551	170	-19727	-32.03	-.14	3.14
			Combined Eff			11551	170	-19727	-32.03	-.14	3.14
		ADIAZ	Eff on Init Mlm		8 meru/g		0			0	
			Eff on Pwr Flt				-3488			-8.99	
			Combined Eff				-3488			-8.99	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$			.3 $meru/g^2$		241			0.39	
		$A^2D_{(SRA)(SRA)Y}$			.3 $meru/g^2$	-991		1652	-2.84		-0.36
		$A^2D_{(IA)(IA)Z}$			.3 $meru/g^2$		-204			-0.59	
Root Sum Square Error (in ft and ft/sec)						23725	51360	83130	101.15	23.66	34.60
" " " " (in n. mi. and ft/sec)						3.90	8.45	13.68	101.2	23.7	34.6

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Table 7-A-14 Uncertainties at Entry End with Update before 1st Burn

	Error			RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		3054			5.45	
		About Y_I		.06 mr	-1062		1304	-3.39		-.50
		About Z_I		.06 mr		-344			-1.41	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	-1633		2262	-3.72		-1.44
	Accel. IA Mlm	Y about X_I		.10 mr		-612			-1.09	
	Bias Error	ACBX	Eff on Init Mlm	.20 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		3519		-8824	7.33		-4.94
			Combined Eff		3519		-8824	7.33		-4.94
		ACBY	Eff on Init Mlm	.20 cm/sec^2		-1170			-4.68	
			Eff on Pwr Flt			-1367			-4.79	
			Combined Eff			-2537			-9.47	
		*ACBZ	Eff on Init Mlm	.20 cm/sec^2	3607		-4426	11.48		1.67
			Eff on Pwr Flt		-4970		25695	-23.38		-9.31
			Combined Eff		-1363		21269	-11.90		-7.63
	Scale Factor Error	SFEX		100 PPM	241		415	.76		2.26
		SFEY		100 PPM		0			-.07	
		SFEZ		100 PPM	-2983		8019	-11.31		-2.05
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-25		-158	-0.12		-0.57
		NCYY		10 $\mu g/g^2$		-11			-0.05	
		NCZZ		10 $\mu g/g^2$	-128		480	-0.43		-0.17
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-891			-1.59	
			Eff on Pwr Flt			2064			8.15	
			Combined Eff			1173			6.56	
		*BDY	Eff on Init Mlm	2 meru	-13	3600	42	-.36	6.42	.10
			Eff on Pwr Flt		-5026	-20	1202	-22.36	.02	-5.38
			Combined Eff		-5039	3580	1244	-22.72	6.44	-5.28
		*BDZ	Eff on Init Mlm	2 meru		-13355			-23.82	
			Eff on Pwr Flt			-4117			-17.06	
			Combined Eff			-17473			-40.88	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		-3565			-6.37	
			Eff on Pwr Flt			1197			-.70	
			Combined Eff			-2368			-7.07	
		*ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		4765		-5924	14.87		1.81
			Combined Eff		4765		-5924	14.87		1.81
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			-2440			-9.69	
			Combined Eff			-2440			-9.69	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g^2		109			0.48	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g^2	-418		483	-1.39		-0.24
		$A^2D_{(IA)(IA)Z}$		meru/g^2		-148			-0.63	
Root Sum Square Error (in ft and ft/sec)					8676	18637	25272	32.99	44.98	11.22
" " " " (in n. mi. and ft/sec)					1.43	3.07	4.16	33.0	45.0	11.2

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Table 7-A-15 Uncertainties at Entry End with Update before 2nd Burn

	Error			RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.50 mr		1210			5.46	
		About Y_I		.06 mr	-260		-143	-1.49		-.44
		About Z_I		.06 mr		-330			-1.41	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.14 mr	0		0	0		0
		X to Z		.14 mr	-9		-376	-.21		-1.56
	Accel. IA Mlm	Y about X_I		.10 mr		241			1.09	
	Bias Error	*ACBX	Eff on Init Mlm	.20 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		-316		-2702	-.85		-4.71
			Combined Eff		-316		-2702	-.85		-4.71
		ACBY	Eff on Init Mlm	.20 cm/sec^2		-1124			-4.80	
			Eff on Pwr Flt			-2601			-4.65	
			Combined Eff			-3725			-9.47	
		*ACBZ	Eff on Init Mlm	.20 cm/sec^2	880		486	9.47		-1.46
			Eff on Pwr Flt		3782		-866	5.04		1.48
			Combined Eff		4662		-380	14.51		.02
	Scale Factor Error	SFEX		100 PPM	179		494	.68		2.26
		SFEY		100 PPM		0			-.07	
		SFEZ		100 PPM	-369		101	-1.51		.29
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-26		-158	-0.12		-0.51
		NCYY		10 $\mu g/g^2$		-11			-0.05	
		NCZZ		10 $\mu g/g^2$	33		-8	0.17		-0.03
GYRO	Bias Drift	BDX	Eff on Init Mlm	2 meru		-353			-1.59	
			Eff on Pwr Flt			1655			8.15	
			Combined Eff			1302			6.56	
		*BDY	Eff on Init Mlm	2 meru	-44	-1700	7	.33	-7.66	-.87
			Eff on Pwr Flt		-3544	2	-1453	-18.87	0	-5.27
			Combined Eff		-3588	-1698	-1446	-18.54	-7.66	-5.36
		*BDZ	Eff on Init Mlm	2 meru		-5201			-23.47	
			Eff on Pwr Flt			-4096			-17.06	
			Combined Eff			-9296			-40.53	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	8 meru/g		-1411			-6.37	
			Eff on Pwr Flt			224			-.70	
			Combined Eff			-1187			-7.07	
		ADSRAY	Eff on Init Mlm	5 meru/g	0		0	0		0
			Eff on Pwr Flt		1101		653	6.23		1.56
			Combined Eff		1101		653	6.23		1.56
		ADIAZ	Eff on Init Mlm	8 meru/g		0			0	
			Eff on Pwr Flt			-2348			-9.70	
			Combined Eff			-2348			-9.70	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g^2		69			0.48	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g^2	-116		-60	-0.67		-0.22
		$A^2D_{(IA)(IA)Z}$		.3 meru/g^2		-143			-0.63	
Root Sum Square Error (in ft and ft/sec)					6014	10651	3226	24.48	44.85	7.84
" " " " (in n. mi. and ft/sec)					0.99	1.75	0.53	24.5	44.9	7.8

[redacted]

TABLE 7-B-1 202 TRAJECTORY INDICATION UNCERTAINTIES

Due to C. M. IMU Component Error Uncertainties where these are equal to latest AGE #17 meas. data

Event	Time from Start mins.	Update Time (Perfect update assumed)	RSS Position Uncert. (n. mi.) Alt.	RSS Position Uncert. (n. mi.) Track	RSS Position Uncert. (n. mi.) Range	RSS Velocity Uncert. (ft/sec) Alt.	RSS Velocity Uncert. (ft/sec) Track	RSS Velocity Uncert. (ft/sec) Range	RSS Flight Path Angle Uncert. deg.
SIVB Cutoff	10.2	1) No update	0.24	1.66	0.16	5.6	38.4	3.5	
SPS 1st Burn Cutoff	14.4	1) No update	0.49	3.34	0.37	8.0	41.8	4.6	
		2) Update prior to SPS 1st Burn	0.03	0.16	0.02	1.4	8.7	1.0	
Coast End (SPS 2nd Burn Ignition)	67.1	1) No update	3.20	3.04	10.17	63.5	37.7	10.7	
		2) Update prior to SPS 1st Burn	0.70	0.08	1.62	10.6	8.4	2.8	
		3) Update prior to SPS 2nd Burn	0	0	0	0	0	0	
SPS 2nd Burn Cutoff	68.6	1) No update	3.14	3.61	10.60	66.7	36.8	11.6	
		2) Update prior to SPS 1st Burn	0.70	0.22	1.72	11.3	9.7	3.1	
		3) Update prior to SPS 2nd Burn	0.01	0.01	0.004	1.1	1.7	0.6	
Entry Start (400,000 ft. altitude)	73.4	1) No update	2.41	5.16	12.00	75.9	25.6	11.6	0.088
		2) Update prior to SPS 1st Burn	0.60	0.68	2.05	13.3	8.6	3.2	0.023
		3) Update prior to SPS 2nd Burn	0.07	0.09	0.03	1.4	1.6	0.4	0.007
									C. E. P. n. mi.
Entry End (24,000 ft. altitude)	87.3	1) No update	4.15	6.70	12.97	100.9	20.6	27.9	11.6
		2) Update prior to SPS 1st Burn	1.12	2.45	2.58	25.5	36.3	6.9	3.0
		3) Update prior to SPS 2nd Burn	0.50	1.45	0.36	14.4	36.2	5.6	1.1

NOTE: Asterisks (*) on detailed tables denote particular IMU uncertainties with most significant effects on position and velocity uncertainties.

<u>AGE #17 Error Uncertainties (1σ)</u>

	X	Y	Z	
Accelerometer bias (ACB)	0.136	0.215	0.066	cm/sec^2
Accelerometer scale factor (SFE)	75	96	150	PPM
Accelerometer non-linearity	10	10	10	$\mu g/g^2$
Gyro bias drift (BD)	2.6	1.4	1.6	meru
Gyro input axis accel. sens. drift (ADIA)	2.5	3.4	2.9	meru/g
Gyro spin ref. axis accel. sens. drift (ADSRA)	4.6	2.0	1.8	meru/g
Gyro accel. squared sens. drift	0.3	0.3	0.3	$meru/g^2$
Accelerometer IA misalignments				
Non-orthogonality X to Y	0.24	---	---	mr.
Non-orthogonality X to Z	0.15	---	---	mr.
Y about X_{SM}	---	0.02	---	mr
Gyro IA misalignment				
Z about X_{SM}	---	---	0.43	mr.

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Table 7-B-2 Uncertainties at SIVB Cutoff with No Update

[redacted]

Error				RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.43 mr		-2302			-8.8	
		About Y_I		0.06 mr	251		-404	1.2		-1.1
		About Z_I		0.06 mr		321			0.8	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.24 mr	0		0	0		0
		X to Z		0.15 mr	869		-242	3.6		-0.94
	Accel. IA Mlm	Y about X_I		0.02 mr		134			0.5	
	Bias Error	*ACBX	Eff on Init Mlm	0.136 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		-868		240	-3.09		0.8
			Combined Eff		-868		240	-3.09		0.8
		ACBY	Eff on Init Mlm	0.215 cm/sec^2		1166			2.7	
			Eff on Pwr Flt			-1241			-4.0	
			Combined Eff			-74			-1.2	
		*ACBZ	Eff on Init Mlm	0.066 cm/sec^2	-279		449	-1.31		1.2
			Eff on Pwr Flt		-113		-364	-0.4		-1.1
			Combined Eff		-392		85	-1.7		0.1
	Scale Factor Error	*SFEX		75 PPM	-457		126	-1.3		0.3
		SFEY		96 PPM		0			0	
		*SFEZ		150 PPM	-237		-771	-1.0		-3.0
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-83		23	-0.2		0.1
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-23		-73	-0.1		-0.3
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		1015			3.9	
			Eff on Pwr Flt			-239			-1.4	
			Combined Eff			776			2.4	
		BDY	Eff on Init Mlm	1.4 meru	2	-2209	0	0.0	-8.4	0
			Eff on Pwr Flt		111	0	-109	0.7	0	-0.5
			Combined Eff		113	-2209	-109	0.7	-8.4	-0.5
		*BDZ	Eff on Init Mlm	1.6 meru		9412			35.8	
			Eff on Pwr Flt			84.9			0.3	
			Combined Eff			9497			36.2	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		976			3.7	
			Eff on Pwr Flt			-252			-1.2	
			Combined Eff			724			2.5	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		-143		125	-0.99		0.7
			Combined Eff		-143		125	-0.99		0.7
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			119			0.5	
			Combined Eff			119			0.5	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 $meru/g^2$		-43			-0.2	
		$A^2D_{(SRA)(SRA)Y}$		.3 $meru/g^2$	31		-28	0.2		-0.1
		$A^2D_{(IA)(IA)Z}$		.3 $meru/g^2$		18			0.1	
Root Sum Square Error (in ft and ft/sec)					1425	10082	965	5.59	38.37	3.49
" " " " (in n. mi. and ft/sec)					0.24	1.66	0.16	5.6	38.4	3.5

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Table 7-B-3 Uncertainties at SPS 1st Burn Cutoff with No Update

	Error			RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.43 mr		-4639			-9.56	
		About Y_I		0.06 mr	405		-809	1.3		-1.4
		About Z_I		0.06 mr		500			0.6	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.24 mr	0		0	0		0
		X to Z *		0.15 mr	1773		-990	4.7		-2.2
	Accel. IA Mlm	Y about X_I		0.02 mr		272			0.6	
	Bias Error	*ACBX	Eff on Init Mlm	0.136	0		0	0		0
			Eff on Pwr Flt	cm/sec^2	-1693		941	-4.55		2.1
			Combined Eff		-1693		941	-4.55		2.1
		ACBY	Eff on Init Mlm	0.215		1815			2.3	
			Eff on Pwr Flt	cm/sec^2		-2371			-4.95	
			Combined Eff			-555			-2.7	
		*ACBZ	Eff on Init Mlm	0.066	-450		899	-1.5		1.5
			Eff on Pwr Flt	cm/sec^2	-430		-604	-1.1		-1.2
			Combined Eff		-879		296	-2.6		0.3
	Scale Factor Error *	SFEX		75 PPM	-771		418	-1.7		0.6
		SFEY		96 PPM		0			0	
		SFEZ		150 PPM	-955		-1352	-2.4		-2.7
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-132		71	-0.3		0.1
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-90		-126	-0.2		-0.2
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6		2045			4.2	
			Eff on Pwr Flt	meru		-658			-1.9	
			Combined Eff			1387			2.3	
		BDY	Eff on Init Mlm	1.4	8.5	-4451	-2.4	0.0	-9.2	-0.0
			Eff on Pwr Flt	meru	267	-0.6	-328	0.99	0	-0.8
			Combined Eff		275	-4452	-331	1.0	-9.2	-0.8
		*BDZ	Eff on Init Mlm	1.6		18964			39.1	
			Eff on Pwr Flt	meru		171			0.3	
			Combined Eff			19135			39.4	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5		1967			4.0	
			Eff on Pwr Flt	meru/g		-591			1.5	
			Combined Eff			1376			2.6	
		ADSRAY	Eff on Init Mlm	2.0	0		0	0		0
			Eff on Pwr Flt	meru/g	-364		419	-1.4		1.1
			Combined Eff		-364		419	-1.4		1.1
		ADIAZ	Eff on Init Mlm	2.9		0			0	
			Eff on Pwr Flt	meru/g		260			0.5	
			Combined Eff			260			0.5	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 $meru/g^2$		-95			-0.2	
		$A^2D_{(SRA)(SRA)Y}$		0.3 $meru/g^2$	78		-92	0.3		-0.2
		$A^2D_{(IA)(IA)Z}$		0.3 $meru/g^2$		40			0.1	
Root Sum Square Error (in ft and ft/sec)					2949	20298	2219	7.96	41.8	4.6
" " " " (in n. mi. and ft/sec)					0.49	3.34	0.37	8.0	41.8	4.6

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Table 7-B-4 Uncertainties at SPS 1st Burn C.O. with Update before 1st Burn

	Error			RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.43 mr		-216			-2.0	
		About Y_I		.06 mr	24		-19.5	0.2		-0.2
		About Z_I		.06 mr		3			0.0	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.24 mr	0		0	0		0
		X to Z		.15 mr	64.9		-40.2	0.6		-0.4
	Accel. IA Mlm	Y about X_I		.02 mr		12.6			0.118	
	Bias Error	*ACBX	Eff on Init Mlm		0		0	0		0
			Eff on Pwr Flt	0.136 cm/sec²	-107.5		65.3	-0.9		0.5
			Combined Eff		-107.5		65.3	-0.9		0.5
		ACBY	Eff on Init Mlm			12.1			0.1	
			Eff on Pwr Flt	0.215 cm/sec²		-195.3			-1.6	
			Combined Eff			-183.2			-1.6	
		*ACBZ	Eff on Init Mlm		-26.6		21.2	-0.3		0.2
			Eff on Pwr Flt	0.066 cm/sec²	-32.5		-50.7	-0.28		-0.4
			Combined Eff		-59		-29.5	-0.5		-0.2
	Scale Factor Error	SFEX		75 PPM	-4.4		2.2	-0.0		0.0
		SFEY		96 PPM		0			0	
		SFEZ		150 PPM	-40		-63.5	-0.4		-0.6
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g²	0		0	0		0
		NCYY		10 μg/g²		0			0	
		NCZZ		10 μg/g²	-2		-2	-0.0		-0.0
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		94.9			0.9	
			Eff on Pwr Flt			-67.6			-0.7	
			Combined Eff			27.3			0.2	
		BDY	Eff on Init Mlm	1.4 meru	0	-207	0	0	-1.9	0
			Eff on Pwr Flt		29.8	0	-22.5	0.3	0	-0.2
			Combined Eff		29.8	-207	-22.5	0.3	-1.9	-0.2
		*BDZ	Eff on Init Mlm	1.6 meru		882			8.1	
			Eff on Pwr Flt			4.9			0.0	
			Combined Eff			887			8.1	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		91			0.8	
			Eff on Pwr Flt			-41			-0.4	
			Combined Eff			50			0.5	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		-42.1		33.3	-0.4		0.3
			Combined Eff		-42.1		33.3	-0.4		0.3
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			8.5			0.0	
			Combined Eff			8.5			0.0	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 meru/g²		-5			-0.1	
		$A^2D_{(SRA)(SRA)Y}$		0.3 meru/g²	9		-7	0.1		-0.1
		$A^2D_{(IA)(IA)Z}$		0.3 meru/g²		1			0.0	
Root Sum Square Error (in ft and ft/sec)					156	956	114	1.41	8.69	1.01
" " " " (in n. mi. and ft/sec)					0.03	0.16	0.02	1.4	8.7	1.0

[redacted]

Table 7-B-5 Uncertainties at SPS 2nd Burn Ignition with No Update

	Error			RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.43 mr		4225			8.6	
		About Y_I		.06 mr	-3861		4980	-6.1		2.9
		About Z_I		.06 mr		-479			-0.5	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.24 mr	0		0	0		0
		X to Z		.15 mr	168		-17568	16.0		2.0
	Accel. IA Mlm	Y about X_I		.02 mr		-247			-0.5	
	Bias Error	* ACBX	Eff on Init Mlm	0.136 cm/sec²	0		0	0		0
			Eff on Pwr Flt		-154		16902	-15.3		-1.9
			Combined Eff		-154		16902	-15.3		-1.9
		ACBY	Eff on Init Mlm	0.215 cm/sec²	-39.1	-1734	278	-0.3	-1.9	0.0
			Eff on Pwr Flt		26	2156	-350	0.3	4.5	0.0
			Combined Eff		-13	422	-71.6	0.0	2.6	0.0
		* ACBZ	Eff on Init Mlm	0.066 cm/sec²	4296	59.6	-5543	6.8	0.1	-3.2
			Eff on Pwr Flt		-8280	-140	23721	-25	-0.2	4.6
			Combined Eff		-3984	-80.8	18178	-18.2	0.2	1.4
	Scale Factor Error *	SFEX		75 PPM	-1231		8683	-8.5		0
		SFEY		96 PPM		0			0	
		SFEZ		150 PPM	-18385		52526	-55.3		10.3
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-256		1529	-1.5		0.0
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-1602	-27	4630	-4.9		0.9
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		-1863			-3.8	
			Eff on Pwr Flt			568			1.8	
			Combined Eff			-1295			-2.0	
		BDY	Eff on Init Mlm	1.4 meru	49.9	4054	-646	0.56	8.3	0.0
			Eff on Pwr Flt		-2190	-26.2	1543	-2.4	-0.0	1.8
			Combined Eff		-2140	4028	896	-1.86	8.2	1.8
		* BDZ	Eff on Init Mlm	1.6 meru	-213	-17272	2753	-2.4	-35.3	-0.1
			Eff on Pwr Flt		-2.5	-157	24.6	-0.0	-0.3	0
			Combined Eff		-215	-17429	2777	-2.4	-35.5	-0.1
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-1791			-3.7	
			Eff on Pwr Flt			525			1.3	
			Combined Eff			-1266			-2.3	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		2953.7		-1905.8	3.1		-2.4
			Combined Eff		2953.7		-1905.8	3.1		-2.4
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			-238			-0.5	
			Combined Eff			-238			-0.5	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 meru/g²		86			0.2	
		$A^2D_{(SRA)(SRA)Y}$		0.3 meru/g²	-621		406	-0.7		0.5
		$A^2D_{(IA)(IA)Z}$		0.3 meru/g²		-36			-0.1	
Root Sum Square Error (in ft and ft/sec)					19397	18484	61806	63.51	37.68	10.66
" " " " (in n. mi. and ft/sec)					3.20	3.04	10.17	63.5	37.7	10.7

[redacted]

Table 7-B-6 Uncertainties at SPS 2nd Burn Ignition with Update before 1st Burn

Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.43 mr		114			1.9	
		About Y_I		0.16 mr	-515		284	-0.5		0.4
		About Z_I		0.16 mr		-3			-0.0	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.24 mr	0		0	0		0
		X to Z		0.15 mr	-1090		178	-0.8		0.9
	Accel. IA Mlm	Y about X_I		0.02 mr		-6.7			-0.1	
	Bias Error	*ACBX	Eff on Init Mlm	0.136 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		1613		-171	1.1		-1.3
			Combined Eff		1613		-171	1.1		-1.3
		*ACBY	Eff on Init Mlm	0.215 cm/sec^2		-9.3			-0.1	
			Eff on Pwr Flt			112			1.6	
			Combined Eff			102			1.5	
		ACBZ	Eff on Init Mlm	0.066 cm/sec^2	573		-315	0.6		-0.5
			Eff on Pwr Flt		-2281		5912	-6.4		1.4
			Combined Eff		-1708		5597	-5.7		0.9
	Scale Factor Error	SFEX		75 PPM	26		13.3	0		-0.0
		SFEY		96 PPM		0			0	
		SFEZ		150 PPM	-3115		8052	-8.7		1.9
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	0		0	0		0
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-128		330	-0.4		0.1
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		-50.7			-0.9	
			Eff on Pwr Flt			33.9			0.5	
			Combined Eff			-16.9			0.2	
		BDY	Eff on Init Mlm	1.4 meru	-14	110	-32.3	0.0	1.8	0.0
			Eff on Pwr Flt		-663	-7.3	357	-0.7	-0.0	0.5
			Combined Eff		-677	102	325	-0.7	1.8	0.5
		*BDZ	Eff on Init Mlm	1.6 meru		-466			-7.8	
			Eff on Pwr Flt			-3.7			-0.0	
			Combined Eff			-470			-7.8	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-48			-0.8	
			Eff on Pwr Flt			22			0.3	
			Combined Eff			-26			-0.4	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		935.7		-508.3	1.0		-0.7
			Combined Eff		935.7		-508.3	1.0		-0.7
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			-6.2			-0.0	
			Combined Eff			-6.2			-0.0	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 $meru/g^2$		3			0.1	
		$A^2D_{(SRA)(SRA)Y}$		0.3 $meru/g^2$	-194		106	-0.2		0.2
		$A^2D_{(IA)(IA)Z}$		0.3 $meru/g^2$		-1			-0.01	
Root Sum Square Error (in ft and ft/sec)					4250	506	9838	10.6	8.4	2.8
Root Sum Square Error (in n.mi. and ft/sec)					0.70	0.08	1.62	10.6	8.4	2.8

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Table 7-B-7 Uncertainties at SPS 2nd Burn Cutoff with No Update

Error				RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.43 mr		5016			8.6	
		About Y_I		0.6 mr	-3870		5667	-6.5		3.0
		About Z_I		0.6 mr		-516			-0.33	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.24 mr	0		0	0		0
		X to Z		0.15 mr	-228		-17375	16.3		2.2
	Accel. IA Mlm	Y about X_I		0.02 mr		-294			-0.5	
	Bias Error	*ACBX	Eff on Init Mlm	0.136 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		250		16700	-15.2		-2.4
			Combined Eff		250		16700	-15.2		-2.4
		ACBY	Eff on Init Mlm	0.215 cm/sec^2		-1878			-1.2	
			Eff on Pwr Flt			2523			3.6	
			Combined Eff			645			2.3	
		*ACBZ	Eff on Init Mlm	0.066 cm/sec^2	4300	67.3	-6307	7.3	0.1	-3.4
			Eff on Pwr Flt		-8012	-162	25025	-26.3	-0.2	4.7
			Combined Eff		-3705	-95	18718	-19.0	-0.2	1.4
	Scale Factor Error	SFEX		75 PPM	-1083		8800	-8.66		-0.2
		SFEY		96 PPM		0			0	
		SFEZ		150 PPM	-17758		55389	-58.5		10.0
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-232	-7	1558	-1.6	-0.01	0.01
		NCYY		10 $\mu g/g^2$		0			0	
		* NCZZ		10 $\mu g/g^2$	-1550	-32	4883	-5.1	0	0.9
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		-2211			-3.8	
			Eff on Pwr Flt			774			2.7	
			Combined Eff			-1438			-1.1	
		BDY	Eff on Init Mlm	1.4 meru	32.9	4814	-647	0.6	8.3	0.04
			Eff on Pwr Flt		-2197	-29.8	1965	-1.8	-0.04	2.3
			Combined Eff		-2164	4784	1317	-1.2	8.3	2.3
		*BDZ	Eff on Init Mlm	1.6 meru	-140	-20507	2759	-2.5	-35.4	0.2
			Eff on Pwr Flt		-1.2	-135	24.6	-0.02	0.8	0
			Combined Eff		-141	-20642	2783	-2.5	-34.6	-0.2
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-2127			-3.7	
			Eff on Pwr Flt			649			1.4	
			Combined Eff			-1478			-2.3	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		3014.7		-2456.4	3.3		-2.6
			Combined Eff		3014.7		-2456.4	3.3		-2.6
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			-262			-0.06	
			Combined Eff			-262			-0.06	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 $meru/g^2$		104			0.2	
		$A^2D_{(SRA)(SRA)Y}$		0.3 $meru/g^2$	-634		521	-0.7		0.5
		$A^2D_{(IA)(IA)Z}$		0.3 $meru/g^2$		-40			-0.01	
Root Sum Square Error (in ft and ft/sec)					19026	21892	64426	66.68	36.77	11.59
" " " " (in n. mi. and ft/sec)					3.14	3.61	10.6	66.7	36.8	11.6

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Table 7-B-8 Uncertainties at SPS 2nd Burn C.O. with Update before 1st Burn

Error				RMS Error	Final Position Error in local Axes (in feet)			Final Velocity Error in local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		0.43 mr		313			2.5	
		About Y_I		0.06 mr	-527		381	-0.5		0.5
		About Z_I		0.06 mr		1.5			0.12	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		0.24 mr	0		0	0		0
		X to Z		0.15 mr	-1132		378	-0.8		0.9
	Accel. IA Mlm	Y about X_I		0.02 mr		-18.5			-0.1	
	Bias Error	ACBX	Eff on Init Mlm	0.136 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		1705		-488	1.7		-1.7
			Combined Eff		1705		-488	1.7		-1.7
		ACBY	Eff on Init Mlm	0.215 cm/sec^2		6.5			0.4	
			Eff on Pwr Flt			227			0.9	
			Combined Eff			233			1.4	
		*ACBZ	Eff on Init Mlm	0.066 cm/sec^2	586		-424	0.5		-0.6
			Eff on Pwr Flt		-2221		6285	-6.6		1.5
			Combined Eff		-1635		5861	-6.1		1.0
	Scale Factor Error	SFEX		75 PPM	33.2		4.4	0.2		-0.1
		SFEY		96 PPM		0			0	
		*SFEZ		150 PPM	-3046		8545	-9.3		1.7
	Accel. Sq. Sensitive Indication Error	NCXX		$10\ \mu g/g^2$	1		0	0.0		-0.01
		NCYY		$10\ \mu g/g^2$		0			0	•
		NCZZ		$10\ \mu g/g^2$	-125		351	-0.0		0.1
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		-138			-1.1	
			Eff on Pwr Flt			137			1.6	
			Combined Eff			-1.3			0.6	
		BDY	Eff on Init Mlm	1.4 meru	-17.1	300	-28.6	0.1	2.4	0.02
			Eff on Pwr Flt		-643	-7.9	498	0.2	-0.01	1.02
			Combined Eff		-660	292	470	0.2	2.3	1.0
		*BDZ	Eff on Init Mlm	1.6 meru		-1280.4			-10.0	
			Eff on Pwr Flt			41.8			1.04	
			Combined Eff			-1238.6			-8.9	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-133			-1.0	
			Eff on Pwr Flt			60			0.5	
			Combined Eff			-73			-0.6	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		956.8		-685.9	0.8		-0.9
			Combined Eff		956.8		-685.9	0.8		-0.9
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			7.1			0.3	
			Combined Eff			7.1			0.3	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		0.3 meru/g^2		8			0.1	
		$A^2D_{(SRA)(SRA)Y}$		0.3 meru/g^2	-198		143	-0.18		0.19
		$A^2D_{(IA)(IA)Z}$		0.3 meru/g^2		1			0.1	
Root Sum Square Error (in ft and ft/sec)					4222	1334	10427	11.28	9.72	3.08
Root Sum Square Error (in n. mi. and ft/sec)					0.70	0.22	1.72	11.3	9.7	3.1

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Table 7-B-9 Uncertainties at SPS 2nd Burn C. O. with Update before 2nd Burn

Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt	Track	Range	Alt	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.43 mr		25			0.56	
		About Y_I		.06 mr	6		4	0.14		0.06
		About Z_I		.06 mr		6			0.14	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.24 mr	0		0	0		0
		X to Z		.15 mr	9.		-5.	0.17		-0.11
	Accel. IA Mlm	Y about X_I		.02 mr		1			0.04	
	Bias Error	ACBX	Eff on Init Mlm	.136 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		15		-10	0.35		-0.23
			Combined Eff		15		-10	0.35		-0.23
		ACBY	Eff on Init Mlm	.215 cm/sec^2		21			0.49	
			Eff on Pwr Flt			-29			-0.64	
			Combined Eff			-7			-0.15	
		ACBZ	Eff on Init Mlm	.066 cm/sec^2	-7		-3	.16		-0.07
			Eff on Pwr Flt		5		7	0.1		0.16
			Combined Eff		-2		4	-0.05		0.09
	Scale Factor Error	SFEX		75 PPM	7		-4	0.13		-0.09
		SFEY		96 PPM						
		SFEZ		150 PPM	-6		-7	-0.11		-0.15
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	1		0	0.01		-0.01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		$\mu g/g^2$	0		0	0		0
GYRO	Bias Drift	* BDX	Eff on Init Mlm	2.6 meru		-10			-0.25	
			Eff on Pwr Flt			44			1.01	
			Combined Eff			34			0.77	
		* BDY	Eff on Init Mlm	1.4 meru	0	-28	0	0	-0.64	0
			Eff on Pwr Flt		43	0	20	0.99	0	0.46
			Combined Eff		43	-28	20	0.99	-0.64	0.46
		BDZ	Eff on Init Mlm	1.6 meru		-100			-2.25	
			Eff on Pwr Flt			47			1.07	
			Combined Eff			-53			-1.18	
	Acceleration Sensitive Drift	* ADIAX	Eff on Init Mlm	2.5 meru/g		-10			-0.24	
			Eff on Pwr Flt			5			0.12	
			Combined Eff			-5			-0.12	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		-12		-6	-.28		-.12
			Combined Eff		-12		-6	-.28		-.12
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			17			.39	
			Combined Eff			17			.39	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 $meru/g^2$		1			0.02	
		$A^2D_{(SRA)(SRA)Y}$		.3 $meru/g^2$	2		1	0.06		0.03
		$A^2D_{(IA)(IA)Z}$		.3 $meru/g^2$		2			0.05	
Root Sum Square Error (in ft and ft/sec)					49	76	26	1.12	1.71	0.58
" " " " (in n. mi. and ft/sec)					0.01	0.01	0.004	1.1	1.7	0.6

Table 7-B-1C Uncertainties at Entry Start with No Update

Error				RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.43 mr		7258			6.07	
		About Y_I		.06 mr	-3444		8039	-8.42		3.11
		About Z_I		.06 mr		-584			-0.11	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.24 mr	0		0	0		0
		X to Z		.15 mr	-1849		-16233	16.43		2.72
	Accel. IA Mlm	Y about X_I		.02 mr		-425			-0.36	
	Bias Error	*ACBX	Eff on Init Mlm	$.136 cm/sec^2$	0	0	0	0	0	0
			Eff on Pwr Flt		1912	-71	15439	-15.38	-0.06	-3.09
			Combined Eff		1912	-71	15439	-15.38	-0.06	-3.09
		ACBY	Eff on Init Mlm	$.215 cm/sec^2$	-11	-2120	292	-0.32	-0.37	0
			Eff on Pwr Flt		-17	3415	-341	0.36	2.31	0.04
			Combined Eff		-28	1295	-49	0.05	1.93	0.04
		*ACBZ	Eff on Init Mlm	$.066 cm/sec^2$	3833	96	-8946	9.36	0.10	-3.45
			Eff on Pwr Flt		-5941	-235	29180	-30.28	-0.24	4.52
			Combined Eff		-2108	-139	20234	-20.92	-0.14	1.07
	Scale Factor Error	SFEX		75 PPM	-325		8999	-9.37		-0.33
		SFEY		96 PPM		0			0	
		*SFEZ		150 PPM	-13345		64501	-67.7		9.7
	Accel. Sq. Sensitive Indication Error	NCXX		$10\ \mu g/g^2$	-103		1675	-1.7	0	0
		NCYY		$10\ \mu g/g^2$		0			0	
		NCZZ		$10\ \mu g/g^2$	-1154		5678	-5.93		0.85
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		-3201			-2.67	
			Eff on Pwr Flt			1530			2.25	
			Combined Eff			-1671			-0.43	
		BDY	Eff on Init Mlm	1.4 meru	-29	6965	-632	0.67	5.83	0.06
			Eff on Pwr Flt		-1795	-43	3410	-2.59	-0.05	2.02
			Combined Eff		-1824	6922	2778	1.92	5.78	2.08
		*BDZ	Eff on Init Mlm	1.6 meru	123	-29673	2694	-2.85	-24.83	-.25
			Eff on Pwr Flt		0	111	25	-.02	.81	0
			Combined Eff		123	-29562	2718	-2.87	-24.02	-.25
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-3077			-2.58	
			Eff on Pwr Flt			1016			1.03	
			Combined Eff			-2061			-1.55	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		2867		-4431	4.70		-2.75
			Combined Eff		2867		-4431	4.70		-2.75
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			-266			.05	
			Combined Eff			-266			.05	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		$.3\ meru/g^2$		156			0.15	
		$A^2D_{(SRA)(SRA)Y}$		$.3\ meru/g^2$	-603		936	-0.99		0.58
		$A^2D_{(IA)(IA)Z}$		$.3\ meru/g^2$		-41			0.01	
Root Sum Square Error (in ft and ft/sec)					14,658	31,367	72,717	75.89	25.57	11.62
" " " " (in n. mi. and ft/sec)					2.41	5.16	12.00	75.9	25.6	11.6

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Table 7-B-11 Uncertainties at Entry Start with Update before 1st Burn

Error				RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.43 mr		1014			2.17	
		About Y_I		.06 mr	-488		732	-0.71		0.50
		About Z_I		.06 mr		37.5			0.11	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.24 mr	0		0	0		0
		X to Z		.15 mr	-1171		1106	-1.40		0.97
	Accel. IA Mlm	Y about X_I		.02 mr		-59.2			-0.13	
	Bias Error	*ACBX	Eff on Init Mlm	.136 cm/sec²	0		0	0		0
			Eff on Pwr Flt		1887		-1755	2.46		-2.02
			Combined Eff		1887		-1755	2.46		-2.02
		ACBY	Eff on Init Mlm	.215 cm/sec²		134			0.40	
			Eff on Pwr Flt			485			0.77	
			Combined Eff			618			1.17	
		*ACBZ	Eff on Init Mlm	.066 cm/sec²	542		-815	0.79		-0.55
			Eff on Pwr Flt		-1678		7502	-7.67		1.43
			Combined Eff		-1136		6688	-6.88		0.88
	Scale Factor Error	SFEX		75 PPM	66.3		-59.7	0.13		-0.16
		SFEY		96 PPM		0			0	
		*SFEZ		150 PPM	-2434		10143	-10.9		1.74
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	4		-5	0.01		-0.01
		NCYY		10 $\mu g/g^2$		0			0	
		NCZZ		10 $\mu g/g^2$	-96		418	-0.43		0.08
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		-447			-0.96	
			Eff on Pwr Flt			612			1.48	
			Combined Eff			165			0.52	
		BDY	Eff on Init Mlm	1.4 meru	-24.4	973	-13	0.01	2.08	0.03
			Eff on Pwr Flt		-311	-12	945	0.12	0.01	0.65
			Combined Eff		-335	961	932	0.12	2.07	0.68
		*BDZ	Eff on Init Mlm	1.6 meru		-4146			-8.86	
			Eff on Pwr Flt			347			.96	
			Combined Eff			-3800			-7.90	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-430			-0.92	
			Eff on Pwr Flt			197			0.42	
			Combined Eff			-233			-0.50	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		880		-1324	1.27		-.91
			Combined Eff		880		-1324	1.27		-.91
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			108			.32	
			Combined Eff			108			.32	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g²		26			0.06	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g²	-182		275	-0.26		0.19
		$A^2D_{(IA)(IA)Z}$		.3 meru/g²		15			0.04	
Root Sum Square Error (in ft and ft/sec)					3,649	4,108	12,463	13.29	8.57	3.23
" " " " (in n. mi. and ft/sec)					0.60	0.68	2.05	13.3	8.6	3.2

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Table 7-B-12 Uncertainties at Entry Start with Update before 2nd Burn

Error					RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
						Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)			.43 mr		188			0.52	
		About Y_I			.06 mr	57		2	0.18		0
		About Z_I			.06 mr		45			0.12	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y			.24 mr	0		0	0		0
		X to Z			.15 mr	40		-57	0.13		-0.16
	Accel. IA Mlm	Y about X_I			.02 mr		11			0.03	
	Bias Error	* ACBX	Eff on Init Mlm		.136 cm/sec^2	0		0	0		0
			Eff on Pwr Flt			83		-117	0.27		-0.33
			Combined Eff			83		-117	0.27		-0.33
		ACBY	Eff on Init Mlm		.215 cm/sec^2		164			0.46	.
			Eff on Pwr Flt				-217			-0.60	
			Combined Eff				-53			-0.14	
		ACBZ	Eff on Init Mlm		.066 cm/sec^2	-63		-2	-0.2		0
			Eff on Pwr Flt			60		35	0.19		0.09
			Combined Eff			-3		34	0.01		0.09
	Scale Factor Error	SFEX			75 PPM	33		-49	0.11		-0.13
		SFEY			96 PPM		0			0	
		SFEZ			150 PPM	-59		-36	-0.19		-0.10
	Accel. Sq. Sensitive Indication Error	NCXX			10 $\mu g/g^2$	3		-5	0.01		-0.01
		NCYY			10 $\mu g/g^2$		0			0	
		NCZZ			10 $\mu g/g^2$	2		1	0.01		0
GYRO	Bias Drift	BDX	Eff on Init Mlm		2.6 meru		-83			-0.23	
			Eff on Pwr Flt				338			0.94	
			Combined Eff				255			0.7	
		* BDY	Eff on Init Mlm		1.4 meru	0	-215	0	0	0.59	0
			Eff on Pwr Flt			391	0	12	1.25	0	0.01
			Combined Eff			391	-215	12	1.25	0.59	0.01
		* BDZ	Eff on Init Mlm		1.6 meru		-756			-2.07	
			Eff on Pwr Flt				358			0.98	
			Combined Eff				-399			-1.08	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm		2.5 meru/g		-80			-0.22	
			Eff on Pwr Flt				39			0.11	
			Combined Eff				-41			-0.11	
		ADSRAY	Eff on Init Mlm		2.0 meru/g	0		0	0		0
			Eff on Pwr Flt			-110		-32	-0.36		0
			Combined Eff			-110		-32	-0.36		0
		ADIAZ	Eff on Init Mlm		2.9 meru/g		0			0	
			Eff on Pwr Flt				129			0.36	
			Combined Eff				129			0.36	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$			.3 meru/g^2		5			0.01	
		$A^2D_{(SRA)(SRA)Y}$			.3 meru/g^2	22		1	0.07		0
		$A^2D_{(IA)(IA)Z}$			.3 meru/g^2		18			0.05	
Root Sum Square Error (in ft and ft/sec)						427	574	152	1.37	1.57	0.41
" " " " (in n. mi. and ft/sec)						0.07	0.09	0.03	1.4	1.6	0.4

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Table 7-B-13 Uncertainties at Entry End (24, 000 ft) with No Update

Error				RMS Error	Final Position Error in Local Axes (in feet)			Final Velocity Error in Local Axes (in ft/sec)		
					Alt.	Track	Range	Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.43 mr		8621			0.19	
		About Y_I		.06 mr	5235		11618	-15.99		-2.55
		About Z_I		.06 mr		-818			-0.87	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.24 mr	0		0	0		0
		X to Z		.15 mr	-549		-11024	12.83		6.43
	Accel. IA Mlm	Y about X_I		.02 mr	2	505	-30	0.03	0.01	0.01
	Bias Error	ACBX	Eff on Init Mlm	.136 cm/sec²	0		0	0		0
			Eff on Pwr Flt		323		8135	-12.83		-10.85
			Combined Eff		323		8135	-12.83		-10.85
		ACBY	Eff on Init Mlm	.215 cm/sec²		-2972			-3.17	
			Eff on Pwr Flt			1140			-7.27	
			Combined Eff			-1832			-10.44	
		* ACBZ	Eff on Init Mlm	.066 cm/sec²	5826		-12931	17.8		2.85
			Eff on Pwr Flt		-8951		32462	-37.3		-10.89
			Combined Eff		-3126		19351	-19.5		-8.04
	Scale Factor Error *	SFEX		75 PPM	-1439		8389	-9.66		-2.06
		SFEY		96 PPM		0			-0.05	
		SFEZ		150 PPM	-23122		72665	-91.8		-22.6
	Accel. Sq. Sensitive Indication Error	NCXX		10 μg/g²	-366		1353	-2.04		-1.22
		NCYY		10 μg/g²		-11			-0.05	
		NCZZ		10 μg/g²	-1935		6350	-7.68		-2.07
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		-3801			-0.08	
			Eff on Pwr Flt			3696			10.04	
			Combined Eff			-105			9.96	
		* BDY	Eff on Init Mlm	1.4 meru	-69	-9862	589	-0.41	-0.21	-0.39
			Eff on Pwr Flt		-5547	-50	5073	-20.9	0.04	-4.23
			Combined Eff		-5616	-9912	5662	-21.3	-0.18	-4.62
		* BDZ	Eff on Init Mlm	1.6 meru	-240	-34649	2069	-1.45	-0.75	-1.38
			Eff on Pwr Flt		1	-3540	12	-0.09	-13.54	-0.43
			Combined Eff		-239	-38189	2081	-1.54	-14.29	-1.81
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-3655			-0.08	
			Eff on Pwr Flt			1227			-0.76	
			Combined Eff			-2428			-0.84	
		* ADSRAY	Eff on Init Mlm	2.0 meru/g	0	0	0	0	0	0
			Eff on Pwr Flt		4612	68	-7877	12.79	-0.06	1.25
			Combined Eff		4612	68	-7877	12.79	-0.06	1.25
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			-1276			-3.29	
			Combined Eff			-1276			-3.29	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g²		241			0.39	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g²	-991		2	-2.84		-0.36
		$A^2D_{(IA)(IA)Z}$		.3 meru/g²		-204			-0.59	
Root Sum Square Error (in ft and ft/sec)					25138	40533	78710	100.88	20.62	27.88
" " " " (in n. mi. and ft/sec)					4.15	6.70	12.97	100.9	20.6	27.9

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Table 7-B-14 Uncertainties at Entry End with Update before 1st Burn

	Error			RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.43 mr		2624			4.69	
		About Y_I		.06 mr	-1062		1304	-3.39		-0.50
		About Z_I		.06 mr		-344			-1.41	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.24 mr	0		0	0		0
		X to Z		.15 mr	-1771		2452	-4.04		-1.57
	Accel. IA Mlm	Y about X_I		.02 mr		-154			-0.27	
	Bias Error	ACBX	Eff on Init Mlm	.136 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		2396		-6008	4.99		-3.36
			Combined Eff		2396		-6008	4.99		-3.36
		ACBY	Eff on Init Mlm	.215 cm/sec^2		-1251			-5.0	
			Eff on Pwr Flt			-1461			-5.12	
			Combined Eff			-2712			-10.13	
		* ACBZ	Eff on Init Mlm	.066 cm/sec^2	1182		-1451	3.76		0.55
			Eff on Pwr Flt		-1629		8422	-7.66		-3.05
			Combined Eff		-447		6971	-3.9		-2.5
	Scale Factor Error	SFEX		75 PPM	181		312	0.57		1.70
		SFEY		96 PPM		0			-0.07	
		SFEZ		150 PPM	-4474		12028	-17		3.08
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-25		-158	-0.12		-0.57
		NCYY		10 $\mu g/g^2$		-11			-0.05	
		NCZZ		10 $\mu g/g^2$	-128		480	-0.43		-0.17
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		-1158			-2.07	
			Eff on Pwr Flt			2683			10.6	
			Combined Eff			1525			8.53	
		* BDY	Eff on Init Mlm	1.4 meru	-9	2520	29	-0.25	4.49	0.07
			Eff on Pwr Flt		-3518	-14	842	-15.7	0.01	-3.76
			Combined Eff		-3527	2506	871	-15.9	4.5	-3.7
		* BDZ	Eff on Init Mlm	1.6 meru		-9630			-19.15	
			Eff on Pwr Flt			-3310			-13.71	
			Combined Eff			-14047			-32.86	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-1114			-1.99	
			Eff on Pwr Flt			374			-0.22	
			Combined Eff			-740			-2.21	
		* ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		1903		-2365	5.94		.72
			Combined Eff		1903		-2365	5.94		.72
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			-893			-3.55	
			Combined Eff			-893			-3.55	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 $meru/g^2$		109			0.48	
		$A^2D_{(SRA)(SRA)Y}$		.3 $meru/g^2$	-418		483	-1.39		-0.24
		$A^2D_{(IA)(IA)Z}$		.3 $meru/g^2$		-148			-0.63	
Root Sum Square Error (in ft and ft/sec)					6,820	14,890	15,621	25.45	36.3	6.87
" " " " (in n. mi and ft/sec)					1.12	2.45	2.58	25.5	36.3	6.9

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Table 7-B-15 Uncertainties at Entry End with Update before 2nd Burn

Error				RMS Error	Final Position Error in Local Axes (in feet) Alt.	Track	Range	Final Velocity Error in Local Axes (in ft/sec) Alt.	Track	Range
STABLE MEMBER	Uncorrelated SM Alignment Errors	About X_I (Azimuth)		.43 mr		1041			4.70	
		About Y_I		.06 mr	-260		-144	-1.49		-0.44
		About Z_I		.06 mr		-330			-1.41	
ACCELEROMETER	Accel IA Nonorthogonality	X to Y		.24 mr	0		0	0		0
		X to Z		.15 mr	-0		-408	-0.23		-1.69
	Accel. IA Mlm	Y about X_I		.02 mr		61			0.27	
	Bias Error	* ACBX	Eff on Init Mlm	136 cm/sec^2	0		0	0		0
			Eff on Pwr Flt		-215		-1839	-0.58		-3.21
			Combined Eff		-215		-1839	-0.58		-3.21
		ACBY	Eff on Init Mlm	.215 cm/sec^2		-1202			-5.13	
			Eff on Pwr Flt			-2781			-4.97	
			Combined Eff			-3982			-10.1	
		* ACBZ	Eff on Init Mlm	.066 cm/sec^2	289		159	3.1		-0.48
			Eff on Pwr Flt		1240		-284	1.65		0.48
			Combined Eff		1528		-124	4.76		0.01
	Scale Factor Error	SFEX		75 PPM	135		371	0.51		1.70
		SFEY		96 PPM		0			-0.07	
		SFEZ		150 PPM	-553		152	-2.26		0.43
	Accel. Sq. Sensitive Indication Error	NCXX		10 $\mu g/g^2$	-26		-158	-0.12		-0.57
		NCYY		10 $\mu g/g^2$		-11			-0.05	
		NCZZ		10 $\mu g/g^2$	33		-8	0.17		0.03
GYRO	Bias Drift	BDX	Eff on Init Mlm	2.6 meru		-459			-2.07	
			Eff on Pwr Flt			2152			10.6	
			Combined Eff			1693			8.53	
		* BDY	Eff on Init Mlm	1.4 meru	-31	-1190	5	0.23	-5.37	-0.06
			Eff on Pwr Flt		-2480	1	-1017	-13.2	0	-3.7
			Combined Eff		-2512	-1189	-1012	-13.0	-5.37	-3.8
		* BDZ	Eff on Init Mlm	1.6 meru		-4181			-18.87	
			Eff on Pwr Flt			-3294			-13.71	
			Combined Eff			-7473			-32.58	
	Acceleration Sensitive Drift	ADIAX	Eff on Init Mlm	2.5 meru/g		-441			-1.99	
			Eff on Pwr Flt			70			-0.22	
			Combined Eff			-371			-2.21	
		ADSRAY	Eff on Init Mlm	2.0 meru/g	0		0	0		0
			Eff on Pwr Flt		440		261	2.49		.62
			Combined Eff		440		261	2.49		.62
		ADIAZ	Eff on Init Mlm	2.9 meru/g		0			0	
			Eff on Pwr Flt			-859			-3.55	
			Combined Eff			-859			-3.55	
	Acceleration Squared Sensitive Drift	$A^2D_{(IA)(IA)X}$		.3 meru/g^2		69			0.48	
		$A^2D_{(SRA)(SRA)Y}$		.3 meru/g^2	-116		-60	-0.67		-0.22
		$A^2D_{(IA)(IA)Z}$		.3 meru/g^2		-143			-0.63	
Root Sum Square Error (in ft and ft/sec)					3,048	8,836	2,206	14.36	36.16	5.62
" " " " (in n. mi and ft/sec)					0.50	1.45	0.36	14.4	36.2	5.6

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8. G&N Performance Data

This section presents brief summaries of the performance of those phases of the Flight 202 mission that are performed under G&N control.

The first part, (Figs. 8-1, 8-2, 8-3, 8-4, 8-5) illustrates performance data which were derived from point mass studies of the G&N guidance and navigation equations using the reference boost trajectory defined in Section 6.2.1.

The second part (Fig. 8-6, Tables 8-1 through 8-8) present performance data derived by perturbing the nominal mission defined by the boost trajectory in the previous issue of this report, with the dispersions listed. Perturbation studies for the current trajectory defined in Section 6.2.1 could not be made in time for the publication of this report, but will be included in a later revision.

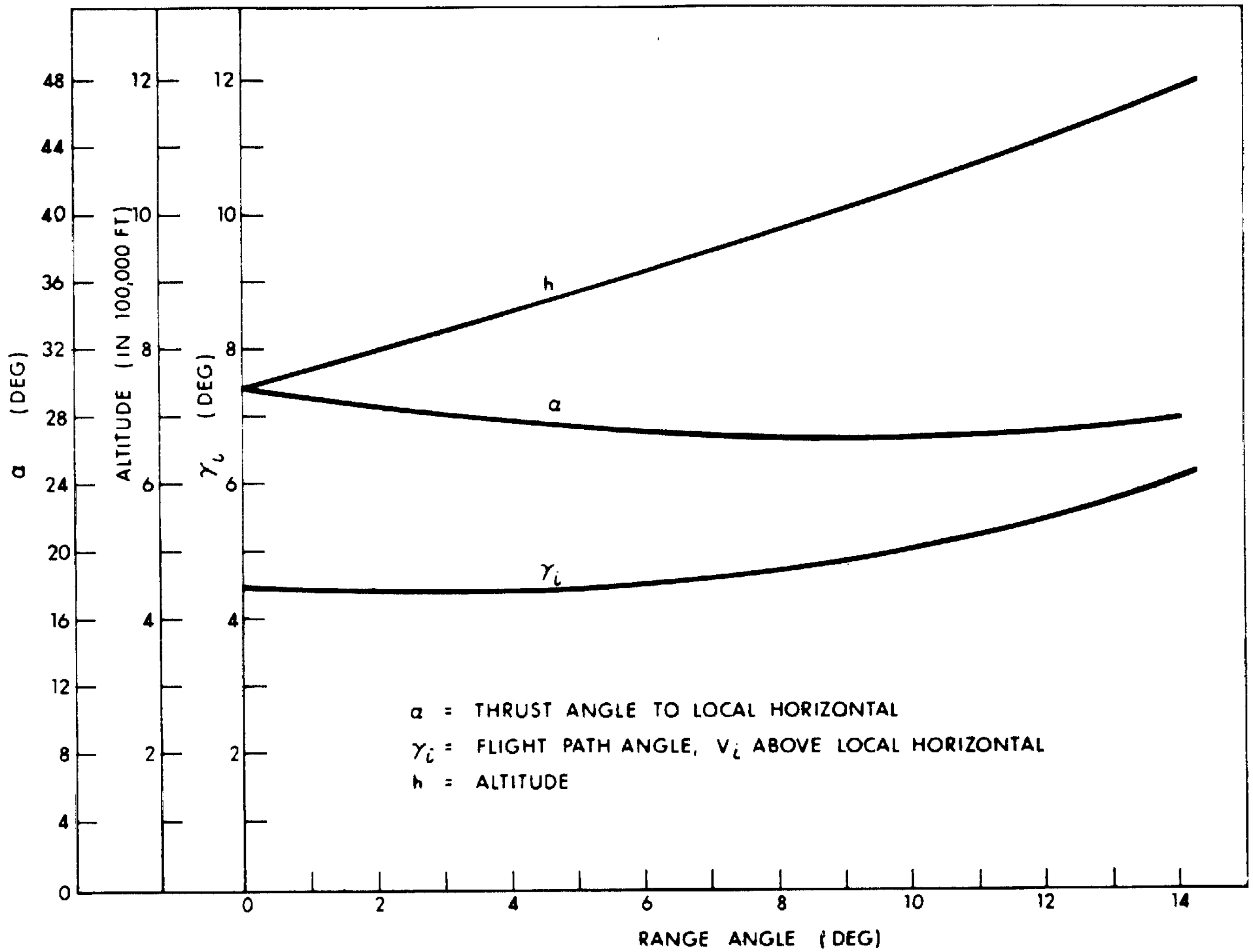

Fig. 8-1 Mission 202 First Burn Trajectory

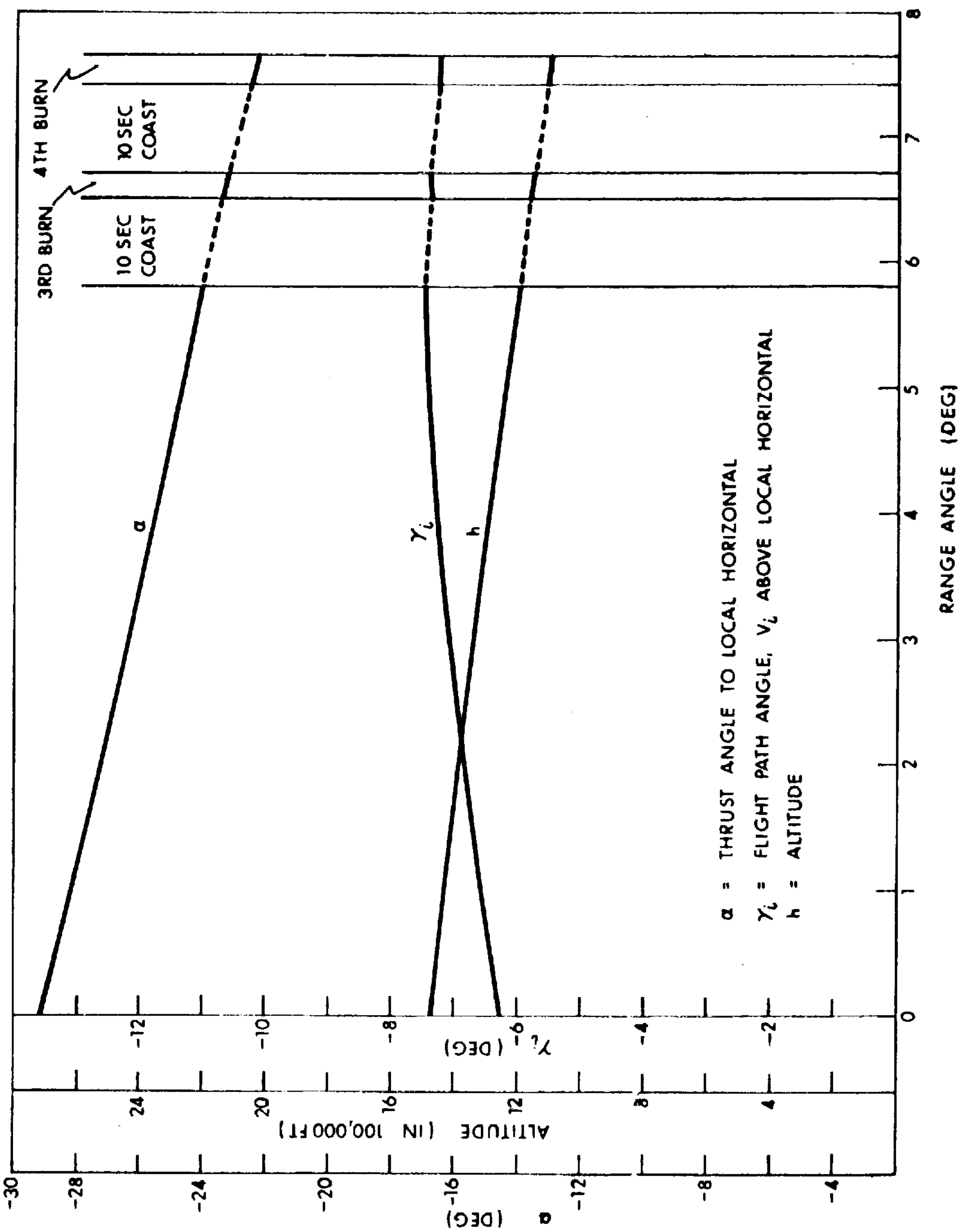

Fig. 8-2 Second, Third and Fourth Burn Trajectory

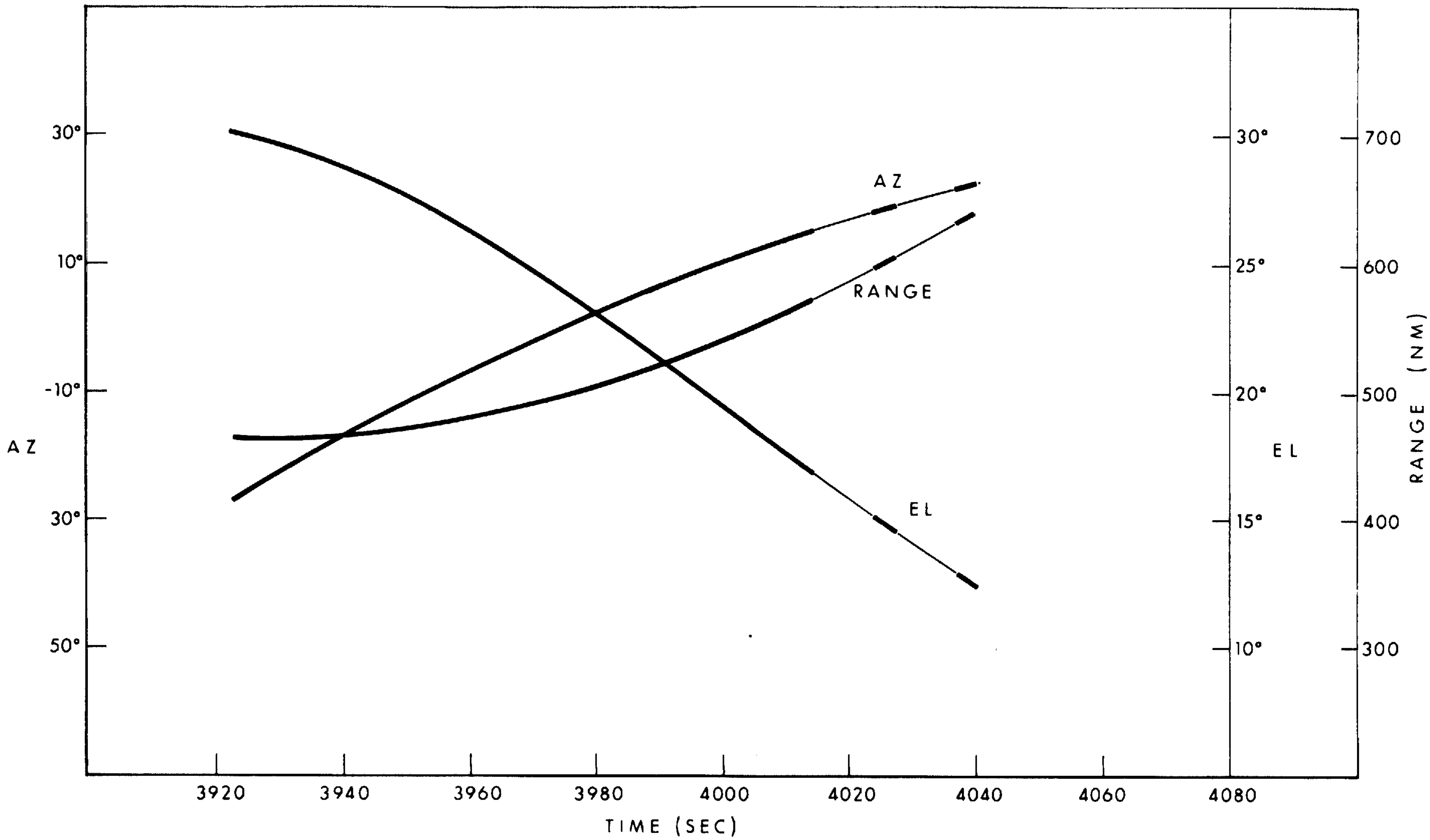

Fig. 8-3 Slant Range Azimuth and Elevation from Carnarvon During 2nd, 3rd, and 4th SPS Burns.

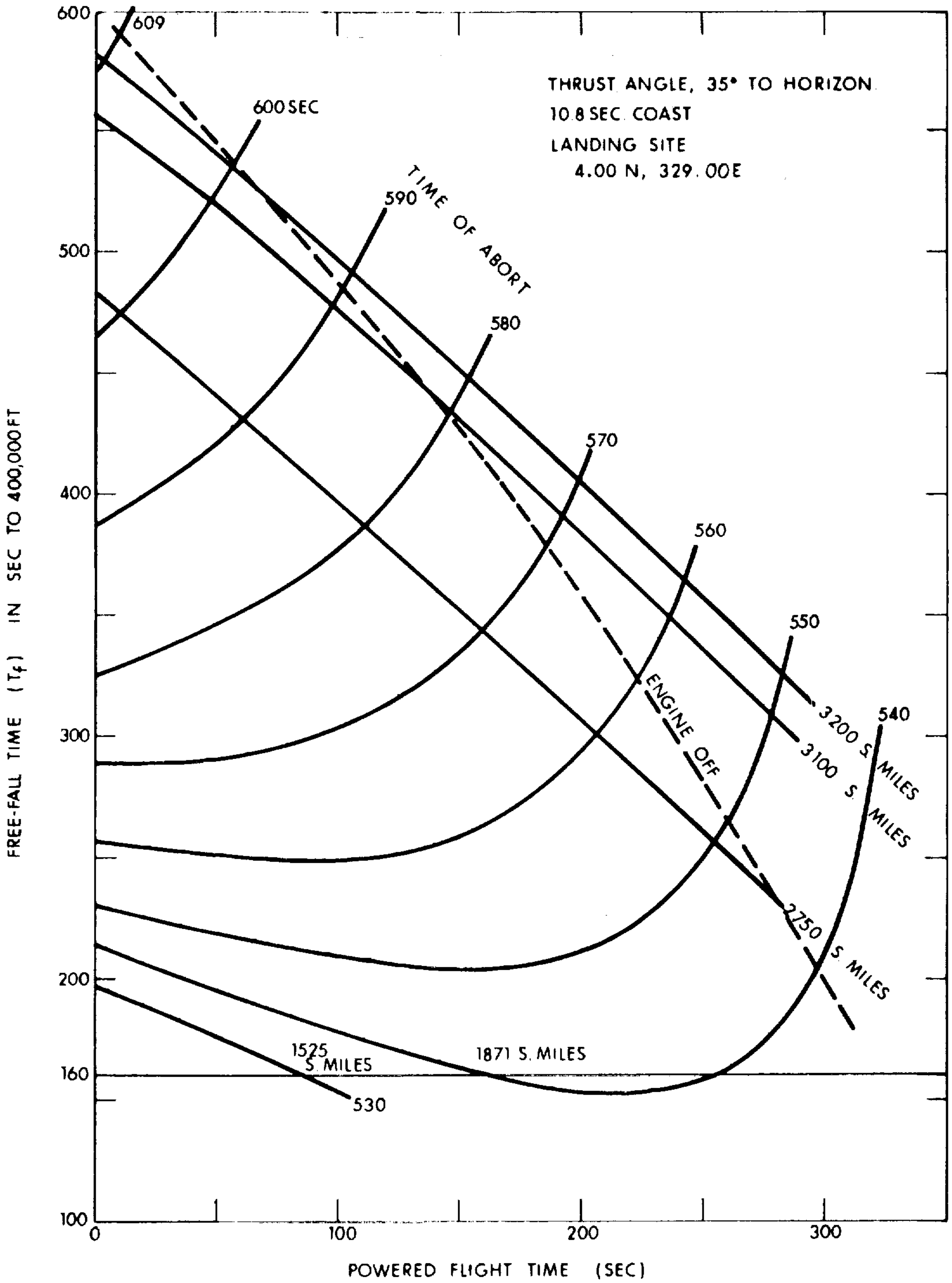

Fig. 8-4 Area Control Capability for Aborts During Saturn Boost

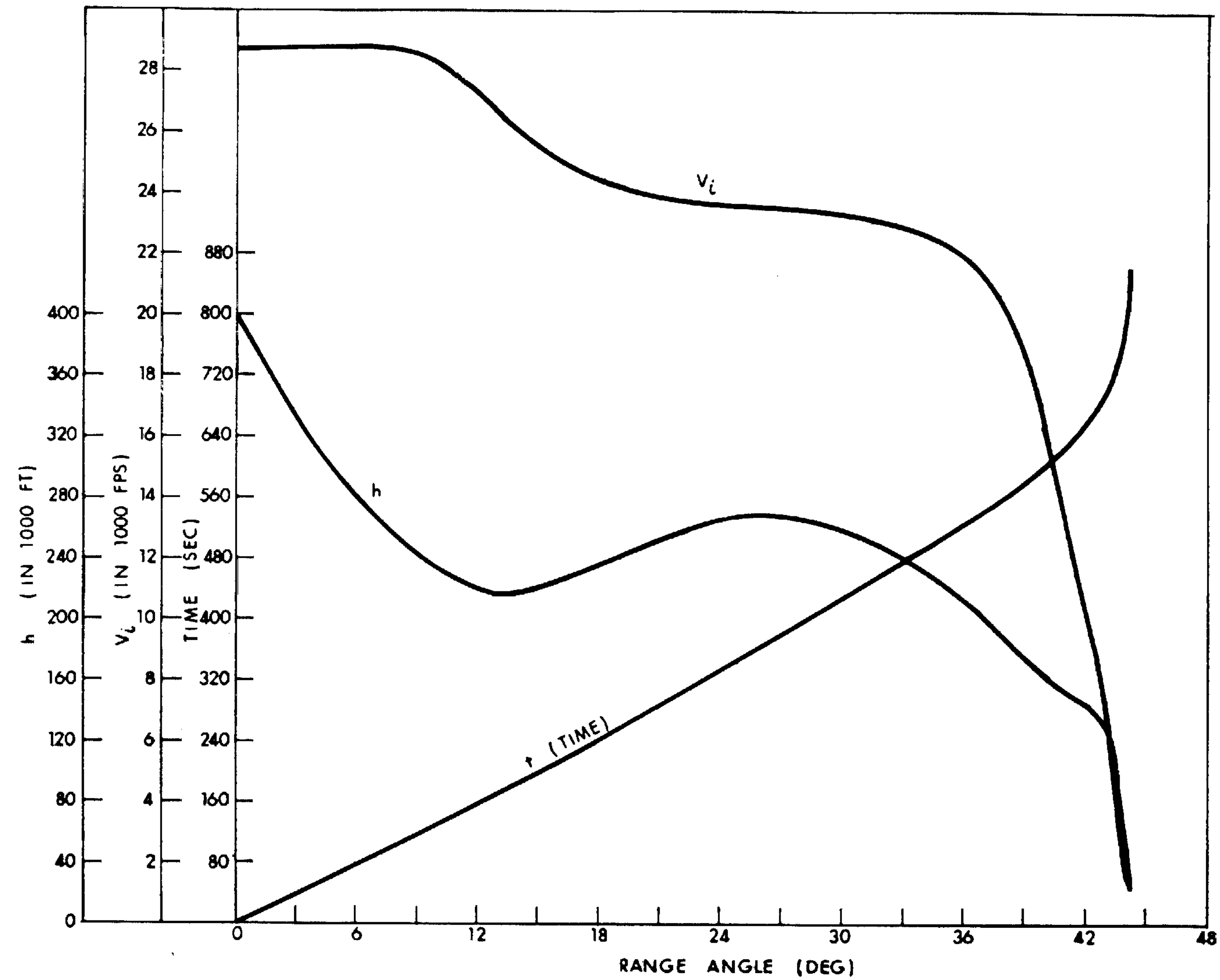

Fig. 8-5 Mission 202 Guided Entry Trajectory.

The data in the Tables 8-1 through 8-8 present performance data derived by perturbing the nominal mission[1] with the dispersions listed on the following page.

The affects of these dispersions are demonstrated in the tables as follows:

Table 8-1	Time, latitude, longitude, altitude, velocity, flight path angle and range (central angle from SIVB cut-off point) at the start of the first SPS burn.
Table 8-2	Same as Table 8-1 at the end of the first SPS burn, plus fuel remaining and burn time.
Table 8-3	Time latitude, longitude, altitude, velocity flight path angle, R, A, and E from Carnarvon at the start of the second SPS burn.
Table 8-4	Same as Table 8-3 at the end of the second SPS burn.
Table 8-5	Same as Table 8-3 at the final cut off.
Table 8-6	Time latitude, longitude, altitude, velocity flight path angle at entry after fourth burn or fuel depletion.
Table 8-7	Velocity and flight path angle at entry without the two short burns.
Table 8-8	Same as Table 8-6 after the first burn only.

The radar at Carnarvon was taken to be at 24.867 S latitude and 113.63 E longitude at a radius of 20,913,669 feet.

The latitude and longitude at entry in Table 8-7 above will be practically the same as Table 8-6 above.

Figure 8-6 shows the track during the nominal second SPS burn and the two short burns. The ignition point and final cut off points of extreme cases are also shown. It should be observed that

a) The maximum westerly dispersion at ignition is about 0.5° longitude.

b) The dispersion in track (213036) cannot be rectified by modification of the second ignition logic.

Any downrange dispersion at SIVB cut-off will move the entire trajectory downrange by the amount of dispersion.

Note 1. See remarks on first page of Section 8.0.

List of Dispersions

Mac Run*	Dispersions
210066	617.4 sec, + 200'/sec inertial velocity
210067	617.4 sec, + 40'/sec inertial velocity
210068	617.4 sec, -40'/sec inertial velocity
210069	617.4 sec, + 3000 ft altitude
210070	617.4 sec, - 3000 ft altitude
210071	617.4 sec, + 0.5^{o} flight path angle
210072	617.4 sec, - 0.5^{o} flight path angle
210073	617.4 sec, + 3 sec I_{sp}
210074	617.4 sec, -3 sec I_{sp}
210075	617.4 sec, + 660 lbs thrust
210076	617.4 sec, -660 lbs thrust
210077	617.4 sec, + 500 lbs weight
210078	617.4 sec, - 500 lbs weight
210890	600 sec, + 30,000 ft. altitude -2^{o} flight path angle -3 sec I_{sp} - 660 lbs thrust + 500 lbs weight
210891	600 sec, negative of above
211683	617.4 sec, nominal
213036	617.4 sec, +1^{o} azimuth -1.63 southern latitude

*Mac Run numbers used in Fig. 8-6.

NOTE:

1. Nominal I_{sp} was increased by 3 seconds over the November figure.

2. All cases have an 11 second coast between SIVB time indicated and SPS 1 ignition.

3. Altitude is in feet
Velocity is in ft/sec
All angles are in degrees
Time is in seconds; total time is measured from lift-off
Range from Carnarvon is slant range in n. m.
Radius of earth used in 20, 925, 738 feet.
The coast time used is 3041 seconds
Precision integration was used during coast

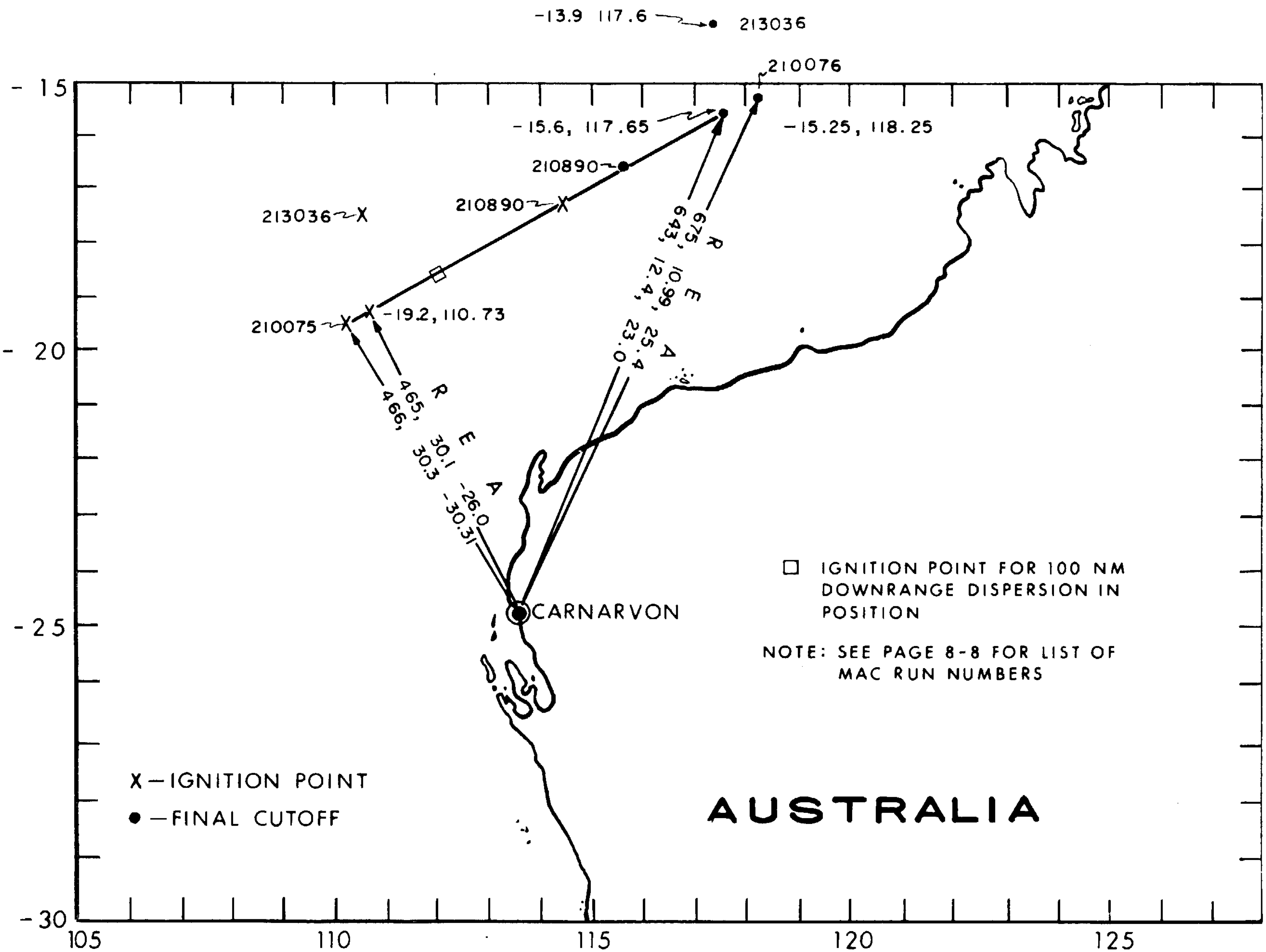

Fig. 8-6 SPS Second Burn Dispersions

Table 8-1

SPS First Burn Ignition

Mac Run	Ignition Time	Lat.	Long.	Arc.	Alt.	V	γ
210066	628.4	23.20	295.19	0.646	555239	22034	2.41
210067	628.4	23.20	295.18	0.641	555138	21874	2.40
210068	628.4	23.20	295.18	0.639	555088	21794	2.39
210069	628.4	23.20	295.18	0.640	558114	21834	2.40
210070	628.4	23.20	295.18	0.640	552113	21834	2.39
210071	628.4	23.20	295.18	0.640	557207	21831	2.90
210072	628.4	23.20	295.18	0.640	553019	21837	1.90
210073	628.4	23.20	295.18	0.640	555113	21834	2.40
to	Same						
210078							
210890	611.0	23.58	294.22	0.607	559265	20715	-4.20
210891	611.0	23.58	294.22	0.607	515147	20692	3.58
211683	628.4	23.20	295.18	0.640	555113	21834	2.40
213036	628.4	21.56	295.17	0.640	555113	21834	2.40

Table 8-2

SPS First Burn Cut Off

Mac Run	Burn Time	Lat.	Long.	Arc	Alt.	V	γ	Fuel Left
210066	244.94	16.68	308.97	15.997	914031	25638	5.77	7525
210067	252,33	16.49	309.30	16.392	918982	25632	5.77	7012
210068	256.00	16.40	309.47	16.586	921243	25629	5.77	6758
210069	254.04	16.45	309.37	16.477	923082	25627	5.77	6894
210070	254.31	16.44	309.39	16.501	917178	25634	5.77	6876
210071	250.00	16.58	309.13	16.197	945703	25601	5.78	7174
210072	258.59	16.30	309.65	16.799	893486	25661	5.76	6578
210073	254.75	16.43	309.41	16.525	921056	25630	5.77	7011
210074	253.59	16.47	309.35	16.452	919192	25632	5.77	6757
210075	245.92	16.68	308.95	15.980	910220	25642	5.77	6943
210076	263.01	16.20	309.85	17.033	930580	25619	5.77	6822
210077	257.27	16.36	309.55	16.680	923819	25626	5.77	7169
210078	251.08	16.54	309.22	16.298	916432	25635	5.79	6599
210890	340.15	14.57	312.77	21.479	752820	25824	5.67	1418
210891	285.16	16.30	309.66	17.833	959525	25585	5.79	4333
211683	254.17	16.45	309.38	16.489	920130	25631	5.77	6884
213036	255.68	14.75	309.29	16.581	921928	25629	5.77	6780

Table 8-3

SPS Second Burn Ignition

							From Carnarvon		
Mac Run	Time	Lat.	Long.	Alt.	V	γ	Range (nm)	Elev.	Azimuth
210066	3914.3	-19.42	110.31	1545371	24920	-5.83	465.1	30.27	-30.20
210067	3921.7	-19.25	110.65	1540221	24925	-5.83	464.6	30.18	-26.86
210068	3925.4	-19.16	110.82	1537872	24928	-5.83	464.9	30.10	-25.22
210069	3923.4	-19.21	110.72	1536144	24930	-5.83	464.4	30.09	-26.18
210070	3923.7	-19.20	110.75	1541913	24923	-5.83	465.0	30.18	-25.89
210071	3919.4	-19.35	110.44	1514190	24955	-5.84	462.1	29.75	-28.95
210072	3928.0	-19.05	111.05	1564895	24898	-5.82	468.4	30.46	-22.94
210073	3924.1	-19.19	110.77	1538141	24928	-5.83	464.7	30.12	-25.74
210074	3923.0	-19.22	110.70	1539997	24926	-5.83	464.7	30.16	-26.35
210075	3915.3	-19.42	110.30	1549110	24915	-5.83	465.5	30.32	-30.33
210076	3932.4	-18.97	111.20	1528456	24938	-5.83	465.9	29.77	-21.48
210077	3926.7	-19.12	110.90	1535303	24931	-5.83	464.9	30.03	-24.43
210078	3920.5	-19.29	110.57	1542763	24922	-5.83	464.8	30.22	-27.65
210890	3992.1	-17.28	114.54	1699460	24747	-5.77	551.8	26.82	6.61
210891	3937.2	-19.08	110.97	1500239	24970	-5.84	462.2	29.39	-23.73
211683	3923.6	-19.21	110.73	1539027	24927	-5.83	464.7	30.14	-26.04
213036	3925.1	-17.40	110.67	1534096	24932	-5.83	533.6	23.34	-20.97

Table 8-4

SPS Second Burn Cut Off

Mac Run	Burn Time	Time	Lat.	Long.	Alt.	V	γ	From Carnarvon		
								Range	Elev.	Azimuth
210066	94	4008. 3	-16. 59	115. 81	1250376	27624	-7. 64	563. 5	17. 33	14. 38
210067	92	4013. 7	-16. 48	116. 03	1251680	27615	-7. 64	573. 1	16. 89	15. 52
210068	91	4016. 4	-16. 42	116. 13	1252555	27610	-7. 64	577. 8	16. 68	16. 06
210069	91	4014. 4	-16. 47	116. 04	1251168	27599	-7. 62	573. 5	16. 86	15. 57
210070	91	4014. 7	-16. 46	116. 06	1256700	27592	-7. 64	575. 0	16. 89	15. 70
210071	92	4011. 4	-16. 58	115. 83	1226923	27640	-7. 56	563. 0	16. 92	14. 48
210072	91	4019. 0	-16. 31	116. 35	1278291	27585	-7. 72	589. 1	16. 62	17. 16
210073	92	4016. 4	-16. 42	116. 14	1249716	27615	-7. 63	577. 9	16. 63	16. 11
210074	91	4014. 0	-16. 48	116. 02	1254557	27610	-7. 65	572. 9	16. 95	15. 48
210075	89	4004. 3	-16. 76	115. 50	1269437	27586	-7. 69	552. 1	18. 27	12. 64
210076	94	4026. 4	-16. 12	116. 68	1234429	27635	-7. 58	601. 7	15. 28	18. 79
210077	92	4018. 7	-16. 34	116. 27	1247262	27607	-7. 62	583. 5	16. 32	16. 77
210078	91	4011. 5	-16. 55	115. 89	1256943	27618	-7. 66	567. 5	17. 26	14. 79
210890	20. 89	4013. 0	-16. 67	115. 68	1643339	25352	-6. 53	589. 0	23. 28	13. 63
210891	61. 27	3998. 4	-17. 27	114. 52	1315852	26950	-7. 35	518. 81	21. 05	6. 47
211683	91	4014. 6	-16. 46	116. 05	1253933	27595	-7. 63	574. 2	16. 88	15. 64
213036	91	4016. 1	-14. 76	115. 98	1248948	27613	-7. 63	668. 8	12. 85	12. 85

Table 8-5

Final Cut Off Conditions

From Carnarvon

Mac Run	Burn Time	Time	Lat.	Long.	Alt.	V	γ	Range	Elev.	Azimuth
210066	100	4034.3	-15.74	117.42	1155966	27904	-7.45	631.2	12.78	22.05
210067	98	4039.7	-15.62	117.63	1157306	27898	-7.45	642.1	12.40	22.90
210068	97	4042.4	-15.56	117.73	1158195	27894	-7.46	647.5	12.22	23.31
210069	97	4040.4	-15.61	117.63	1157013	27882	-7.44	642.6	12.38	22.93
210070	97	4040.7	-15.60	117.66	1162358	27875	-7.46	644.2	12.41	23.03
210071	98	4037.4	-15.71	117.44	1133495	27921	-7.37	631.2	12.42	22.12
210072	94.92	4042.9	-15.51	117.81	1190537	27797	-7.52	653.6	12.50	23.63
210073	98	4042.1	-15.55	117.74	1155440	27897	-7.45	647.7	12.17	23.34
210074	96.57	4039.6	-15.63	117.59	1161644	27874	-7.46	640.7	12.52	22.76
210075	95	4030.3	-15.90	117.10	1174504	27875	-7.51	617.3	13.63	20.71
210076	100	4052.4	-15.25	118.28	1140699	27913	-7.39	675.1	10.99	25.39
210077	96.24	4042.9	-15.54	117.76	1159533	27828	-7.41	649.0	12.18	23.42
210078	97	4037.5	-15.69	117.49	1162261	27903	-7.48	635.6	12.72	22.35
211683	97	4040.6	-15.60	117.65	1159684	27878	-7.45	643.4	12.39	22.98

Table 8-6

Final Entry Conditions

							At 400, 000 ft Altitude	
Mac Run	Time	Lat.	Long.	Alt.	V	γ	V	γ
210066	4314	-5. 26	134. 7	394160	28711	-3. 47	28702	-3. 49
210067	4320	-5. 13	134. 9	394943	28706	-3. 48	28698	-3. 50
210068	4322	-5. 07	135. 0	395452	28703	-3. 49	28695	-3. 50
210069	4320	-5. 13	134. 9	395282	28690	-3. 49	28682	-3. 50
210070	4321	-5. 12	134. 9	397910	28686	-3. 52	28680	-3. 50
210071	4307	-5. 63	134. 1	400988	28699	-3. 53	28697	-3. 50
210072	4333	-4. 67	135. 6	395489	28642	-3. 51	28634	-3. 52
210073	4322	-5. 06	134. 0	394113	28705	-3. 48	28695	-3. 50
210074	4320	-5. 16	134. 9	397455	28690	-3. 51	28684	-3. 50
210075	4310	-5. 46	134. 4	403404	28693	-3. 56	28693	-3. 50
210076	4323	-5. 10	134. 9	403655	28695	-3. 56	28696	-3. 50
210077	4323	-5. 07	135. 0	398082	28637	-3. 54	28632	-3. 52
210078	4317	-5. 21	134. 8	396989	28715	-3. 50	28708	-3. 49
210890	4484	-5. 26	141. 8	403303	26749	-4. 79	26748	-4. 75
210891	4332	-5. 35	134. 5	403340	27941	-3. 93	27940	-3. 88
211683	4321	-5. 13	135. 0	396594	28688	-3. 50	28681	-3. 50
213036	4322	-3. 84	135. 0	393717	28704	-3. 48	28695	-3. 50

Table 8-7

Entry Conditions (400, 000 ft) After Second Burn
(no short burns)

Mac Run	V	γ
210066	28497	-3. 57
210067	28518	-3. 57
210068	28514	-3. 57
210069	28502	-3. 57
210070	28501	-3. 57
210071	28518	-3. 57
210072	28515	-3. 56
210073	28516	-3. 57
210074	28516	-3. 57
210075	28508	-3. 57
210076	28520	-3. 57
210077	28506	-3. 57
210078	28526	-3. 56
211683	28501	-3. 57
213036	28514	-3. 57

Table 8-8

Entry Conditions After First Burn
(No Second Burn)

Mac Run	Time	Lat.	Long.	Alt.	V	γ
210066	4364	-4.76	135.3	399677	26241	-5.34
210067	4371	-4.58	135.6	397107	26244	-5.34
210068	4374	-4.48	135.7	394821	26246	-5.34
210069	4372	-4.54	135.6	393152	26248	-5.34
210070	4373	-4.53	135.7	398742	26242	-5.34
210071	4358	-5.04	134.9	396344	26245	-5.34
210072	4387	-4.02	136.4	396602	26244	-5.34
210073	4373	-4.51	135.7	395084	26246	-5.34
210074	4372	-4.55	135.6	396887	26244	-5.34
210075	4367	-4.70	135.4	398418	26242	-5.34
210076	4381	-4.24	136.1	385683	26257	-5.33
210077	4376	-4.43	135.8	392327	26249	-5.34
210078	4369	-4.64	135.5	399577	26241	-5.34
211683	4373	-4.53	134.7	395945	26245	-5.34
213036	4374	-3.24	135.7	390864	26251	-5.34

The entry conditions at 400,000 feet are 26237 ft/sec 5.34° for all cases.

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